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LAHORE,

1930.

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MEMBERS OF THE COUNCIL.

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(1930-31.)

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President, 1929-1930.



WILLIAM STEWART DORMAN,
President, 1929-1930.

ADDRESS

OF

Mr. W. S. DORMAN,

PRESIDENT.

Gentlemen,

It is my privilege, as President of the Punjab Engineering Congress, to express on your behalf the pleasure it gives us all to welcome here, this morning, to open the Congress, the Hon'ble Khan Bahadur Mian Sir Fazl-i-Husain, Revenue Member of the Punjab Government.

Sir Fazl-i-Husain is an old friend and his services to the Province are too well-known to need recapitulation, but as I understand that before we meet for our next Congress he will have left us to undertake still higher office and greater responsibilities with the Central Government, I should like to offer him our good wishes and to say how greatly we shall miss his official guidance and more particularly his leadership in the Legislative Council

I should also like to welcome the Hon'ble Sir Alexander Stow, who perhaps will permit me to take this opportunity, the first which we have had of meeting him in our corporate capacity, to congratulate him on having been made a Knight Commander of the Most Eminent Order of the Indian Empire ; and the Hon'ble Ministers, who year by year find time to show their interest and encourage us by their presence. We more particularly welcome our esteemed friend the Hon'ble Minister for Agriculture who is so intimately connected with my own Branch of the Public Works Department and to whom you will also wish me to tender our most hearty congratulations that his labours for the welfare of the Province should have been recognised by the honour of a Knighthood. To the other distinguished visitors who have been able to accept the invitation of your Council to honour us with their presence here this morning I would also extend a hearty welcome. It is a particularly great pleasure to see our old friend Mr. Foy.

The thought that this is our eighteenth Congress engenders feelings [illegible]

he remains true to himself all will be well.

During the year, death robbed us of one active member—one who while he was in India never failed to combine attendance at the Congr

Gentlemen, It is always difficult for your President to know what to say when he addresses you on these occasions. Few have such a wealth of material at their disposal as Col Craster (who did so much for the Congress) had in 1917, when he gave that masterly review of 31 years' progress on the North Western Railway since various lines were amalgamated to form that great system in 1886. Several Presidents have been content to anticipate the administration reports by giving a brief record of the previous years' activities, and I must say it is a temptation to tell you of the 235 miles of new line opened to passenger traffic by the North Western Railway administration during the year; of the progress which they are making on bridging the Indus at Kalabagh, the Jhelum at Khushab, and the Chenab at Chiniot, after having completed new bridges over the Ravi at Narowal, and over the Sutlej at Ferozepur, and reconstructed the bridges across the Indus at Attock and over [illegible] also enlarge on the 7 million odd acr[illegible] or of the 6 million odd acres irrigated [illegible] to state that the irrigation of the British portion of the Sutlej Valley canals alone amounted to over 11 lakhs of acres during 1929-30, which, considered in crop values, comes to approximately Rs. 500 lakhs increase in the annual income of the Punjab The total value of crops raised on all canals during 1929-30 was Rs. 5,506 lakhs This is based on a yield of Rs. 46 an acre.

The Sutlej Valley Project is now approaching completion and the final diversion of the combined Chenab and Sutlej waters over the last weir would probably have been in progress had it not been for the alarming floods in August. Mr. Gunn describes the flood resulting from the bursting of the Shyok Dam, [illegible] up for discussion just now, [illegible] that this flood did not synch[illegible] from more local rain which [illegible] caused damage amounting tc [illegible] in charge of the Irrigation and General Branches of the Public Works Department and on the North Western Railway alone, in addition to a loss, estimated at Rs 25 lakhs, in traffic earnings on the railway.

For my own part, however, I prefer to hark back for inspiration to Mr. Montgomery's attempt in 1920 to forecast what the future had in store for the Province. Mr. Montgomery thought the Lyallpur grain elevator, with its storage capacity of 100,000 maunds of wheat, would be the forerunner of similar elevators in all the large grain producing centres of the Province, once the railway and port authorities realised the enormous advantage of bulk transp[illegible] system of lines of surface [illegible] railway, and of shallow [illegible] which he thought likely, now appear to be unlikely lines of development. The great expansion in the road system, however, which he foresaw, with roads rivalling in importance the old imperial trunk road from Delhi

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with his annual training in the Punjab Light Horse Camp and whose premature death must be very largely attributed to his devotion to duty. I refer to Alexander Edmund Knox

Eight members have resigned—mostly on leaving India, and four, I am sorry to say, have had to be struck off the roll as defaulters, but despite all this, if I take into account all the most recent applications for membership, some of which are still under the consideration of the Council, we have had a nett increase of nearly 60 since 1st January 1929, bringing our membership up to close on 400.

Before I pass on to more general matters, on behalf of the Congress I should like to congratulate Mr Walker, C.I.E., Rai Bahadur Ganpat Rai and Khan Sahib Abdur Rahman, on the honours which they have received during the year, and also to thank here publicly Mr. Robertson, most efficient of honorary secretaries, for a year's exceedingly strenuous

several years' devot-
I sure that our other
nobly, will forgive me

if I spare their blushes.

I do not know how it came about that we originally adopted the slogan of "

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Progress denotes life, while life to be worth the name must be active, but I think that the growth in our membership, the presence of the large crowd here today and lively discussions on the papers to follow will show, I hope, that we are very much alive. Moreover, it is only by pooling our resources and working together, with each one doing his part, that we can make satisfactory progress and this yearly Congress provides the opportunity for men to contribute their quota towards the common stock of knowledge, either by presenting papers for discussion or contributing from their experience to the discussions on these papers and, thereby, enabling us all better to fulfil our destiny as engineers, in directing the great sources of power in nature for the use and convenience of man. Never before have we had so many papers presented to the Congress that the Council has been able to pick and chose to an extent not hitherto possible, and I am glad to say that an increased number of contributions have been by young Punjabi engineers, but, not having the figures by me, I am unable to say whether each community has contributed its proper quota. This year we have also been fortunate enough to secure a paper on a subject closely akin to engineering from two well-known Forest officers, Messrs. Holland and Glover, which will be discussed this afternoon, but it is not only Forest officers whose co-operation we need for our technical work. Our dependence on the physicist, the chemist and the geologist is obvious. To the researches of zoologists we owe the successful construction of the Panama Canal and the designers of our aeroplanes had to call on the botanists for advice in the selection of their wing materials.

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to Attock—roads radiating from Lahore to Multan, to Bhakkar, to Khushab and so forth, has made substantial progress, though, as Sir Edward Maclagan then reminded us (and it is something which is now being brought home to us once again) progress in such matters depends on the auspicious conjunction of three planets—the provincial balance, the staff and the ways and means—and it was seldom we got the time and the place and the loved one all together.

... the Attock ... and ... but even using oil for brick burning He was on firmer ground, however, when he spoke of electrical developments and of the fillip which the establishment of the cement factory in the north of the Province would give to the use of Portland cement

In the last five years the consumption of cement in the Province has more than doubled, and last year (1929), in the Second Circle alone, we used nearly 30,000 reinforced concrete battens for our flat mud roofs, while reinforced concrete slab or girder and slab construction is rapidly superseding the time honoured brick arch in all new bridge and culvert work. The fact that 1929 has seen steel sleepers used for the first time in any quantity on English railways, where their longer life has proved their ultimate economy, suggests that the day may not be far distant when reinforced concrete will displace wood for the sleepers of our Indian railways, and, that the consequent decreased demand for timber will help ... the deplorable state ... to some of the fairest ... set forth in the paper ... ng for discussion this afternoon.

Col. Battye's paper, which will be coming up for discussion just now, tells us how the waters of the River Uhl in Mandi are being harnessed for the service of the Punjab, and a few years should see the electrical developments, fore... power from the U... plants, which have ... or 15 years.

... cation is perhaps the ... bringing the peoples ... main unifying factor of the future.

The air-ship R-100 with her six Rolls Royce Condor engines, deve-
100 pas-
nable her
ree days,
re already
considered past our work, actually flew from England to Karachi and back in an aeroplane in 7½ days

The Blue Riband of the Atlantic, after being held by the Mauretania for 22 years, has just been wrested from us by the German-built Bremen, but the Cunard Shipping Company is already planning a 30-knot liner with which it hopes to re-establish its supremacy Sir Henry Segrave, however, has pointed out that, whereas during the last 20 years motors have more than doubled their speed and airplanes have learned to travel five times as fast, shipping has remained practically stationary for many years, and only a complete change of design will enable ships to improve appreciably on their present performances Instead of ploughing her way forward, half submerged, through the water, the ship of the future must come out of the water and travel on the surface He may have had in mind something similar to the German Dornier's flying boat, with a maximum speed of 150 miles per hour, a cruising speed of 100 miles and sleeping accommodation for 40 passengers.

Germany has also produced a giant land plane, able to transport, three tons of freight, 2,500 miles, at a speed of over 125 miles an hour.

Aviation, however, had its birth in the United States of America, on 17th December 1903, when Orville and Wilbur Wright flew a biplane a distance of some 825 feet, at Kitty Hawk in North Carolina, but the failure, in 1920, of the services between New York and a number of almost equally well known places to pay their way showed that the Americans had not then became air-minded Between 1920 and 1927, Germany's air traffic increased 30-fold while America had made little progress, then suddenly, with Colonel Lindbergh's flight across the Atlantic, America

that aircraft construction companies
it is difficult to keep pace with
ow well lighted air mail routes
between the Atlantic sea-board and the Pacific coast, and the wealthy traveller, in a hurry, can get from Los Angelos to New York and back in four days by a regular mail aeroplane, thereby saving a full week's time,
tho Our own Empire's
air 1929,
anc mpire
Le ld see
35,000 miles in operation.

There have been some appalling disasters, such for example as the one last June when seven passengers lost their lives in a forced descent while "City of Jerusalem," neward air mail, the

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for

With the world being girdled by air routes in this way I do not think

saving in time resulting from the development of roads, railways and motor traffic, all over the country, pointed out how air travel, both official and private, has become accepted as part of the transport system of the country and that landing grounds now exist at all the important, and at many of the smaller places in the Sudan.

Business men have already proved the value of aeroplanes out here,

zamindar is getting all the water he wants Landing grounds may be a difficulty for a time, but there is every hope that this will soon be overcome and that the aeroplane owner will be able to descend on, or rise from, a very small area, possibly even the flat roof of his bungalow.

The aeroplane will also be of further practical use to the engineer.

for locating under-water formations, and I believe it has been used in the United States for locating high tension transmission lines and for

Turning for a moment to the railways These after having more or less marked time for some years are now waking up under the stimulus of the competition from motor traffic—On the North Western Railway this is being met by introducing additional train services, by reducing rates and by publicity propaganda There has also been a general speeding up of passenger and goods train services and the strengthening of the main line track and bridges, now in hand, will admit using still heavier types of engines capable of hauling greater loads at higher speeds. Next September, the new 4-6-2 Pacific type engines, weighing 176 tons,

having a traffic effort of 32,000 lb and an axle load of 20 tons, will be in operation between Peshawar, Lahore and Karachi, and I understand this type of engine will be a great advance upon anything hitherto used on Indian railways.

Efforts are also being made to cater better for the creature comforts and for the health of the travelling public, amongst other ways, by providing pure drinking water supplies, by means which Mr Vardon will explain to-morrow It may be we shall soon have artificial cooling for hot weather travel somewhat on the lines of the 'frigicar' of the North American Car Company, in which the temperature is apparently automatically controlled, at any fixed desired level, by means of an ammonia compressor, worked by a mechanical drive off one of the axles, which also stores a sufficient reserve in brine tanks to tide over periods when the car may be at a stand still. Such a system would soon oust fans which stir up dust and induce chills.

There has been a notable quickening up in English passenger train schedules, but the delays in goods traffic have caused much to be diverted to the road and a determined effort is now being made to recover the ground lost and in fact to pool all goods traffic.

I read somewhere the other day that the London and North Eastern Railway is at present experimenting with a rail-plane intended to carry passengers at 120 miles an hour Dependent from and guided by rails, [illegible] en by two aeroplane [illegible] is said to be only a [illegible] successful it should revolutionize railway travel

There is also a movement on foot in England to eliminate most, if not all, level crossings, but that brings me to the subject of roads.

[illegible] past week about the shortcomings of our roads. I only propose to touch on one or two points.

[illegible] miles in excess of the coach, with a great deal more acceleration, and the [illegible] the brakes for controlling these high speed cars are quite up to their [illegible]

to this country new, it is common knowledge

one another comfortably, and, where the metalling is not wide enough to take two lanes of traffic, that the berms be maintained in perfect order.

Another problem is the education of all bullock cart drivers to keep to their proper side of the road, or sufficiently awake to realise

parallel tracks cattle on the for them at the side.

It is however in the towns and villages, of course, where there is most congestion and where only the fullest co-operation between the road authority, the police and the local authority (where one exists) will effect cal authority is rarely alive to its the natural tendency for a town is ssing through it Propaganda is necessary to persuade it that development at right angles to the road, where there will be less dust and danger from passing traffic, is pre-

the police, and the provision of such conveniences is another matter for early attention.

I have dealt mainly with communica-

nication that the world so la

—whether we consider it

aphorism

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facilities and er Henry Thornton said the other day "it's keeping your eye open for to-morrow that builds a country or a business—that, and knowing what you're doing to-day" But, Gentlemen, I do not wish to end in a purely materialistic concept of progress, which appears to have found its supreme expression in that land of rush and hurry—the United States of America—and which is so far removed from that under-current of spiritual life which we like to associate with

the East, and which I should like to see reflected more in our work. Sir Benjamin Brodie, addressing the Royal Society in 1859, said that physical investigation more than anything besides, helped to teach us the actual value and right use of imagination, which, if properly controlled by experience and reflection, became the noblest attribute of man, the source of poetic genius and the instrument of discovery in science.

Some of us are nearing the end of our time in the service of the Punjab while others are [illegible] like to leave this [illegible] the formation of [illegible] meaning as it does that every action has its effect and every job carried out has an importance far greater than its intrinsic worth. Work therefore [illegible] work [illegible] digni- [illegible] ter and which will give pleasure to generations yet unborn.

You may or may not receive recognition for your work. That is a secondary matter Do the work for your own credit and for the glory of this great and progressive Province which we all love and seek to serve.

SPEECH.

BY

THE HON'BLE KHAN BAHADUR,

MIAN SIR FAZL-I-HUSAIN, K.C.I.E., Kt.,

MEMBER FOR REVENUE.

Members of the Engineering Congress and Gentlemen :—

I am very glad
in this great hall to-
members to this ann

not deny myself the pleasure of availing myself of this opportunity of paying my tribute to a great profession, the wonderful work of which in one branch I came to know as Revenue Member

The Engineering Congress has now become an annual institution in the intellectual activities of the province; and there can be no two opinions about the very great utility of the institution It is making most valuable contributions to engineering knowledge and research The daily work of a large number of you is in remote parts of the province and a free and frank discussion on engineering subjects cannot but whet your wits, infuse enthusiasm and zeal, reclaim you from the monotony of the routine part of your work and invite you to efforts of investigation and invention. Discussion is verily the one method by which knowledge is enhanced and the capacity and talent called upon to make fresh efforts at self-realization

The importance of your profession is ever-increasing; your struggle with nature is getting more acute. You have made many conquests in the past, and we trust you have many more to make, but the resources of nature are unlimited and for years and years to come there will always be something for you to conquer. The scope of your activities is unlimited; and there is hardly any sphere of human activity which can be developed without your co-operation. In communications of all

of wealth as yours—whether that production of wealth is through land or through factories, your share in that production is greater than that of any other profession Not only do you contribute towards production of wealth, but society is beholden to you also for facilities for marketing.

SPEECH.

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THE HON'BLE KHAN BAHADUR,

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MEMBER FOR REVENUE.

Members of the Engineering Congress and Gentlemen :—

I am very glad to see the engineering talent of the P[illegible] in this great hall to-day and I [illegible]

[illegible]

of office as Revenue Member of the Punjab Government, I felt I could not deny myself the pleasure of availing myself of this opportunity of paying my tribute to a great profession, the wonderful work of which in one branch I came to know as Revenue Member.

The Engineering Congress has now become an annual institution in the intellectual activities of the province; and there can be no two opinions about the very great utility of the institution. It is making most valuable contributions to engineering knowledge and research. The daily work of a large number of you is in remote parts of the province and a free and frank discussion on engineering subjects cannot but whet your wits, infuse enthusiasm and zeal, reclaim you from the monotony of the routine part of your work and invite you to efforts of investigation and invention. Discussion is verily the one method by which knowledge is enhanced and the capacity and talent called upon to make fresh efforts at self-realization.

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There is no other profession which makes a more direct contribution to national wealth than yours.

It is but natural that a profession with such wide possibilities should attract the best material, and yet there are certain popular fallacies which it is time should be exploded. It is generally believed that a boy who has a mechanical turn of mind will do for engineering, implying thereby that all that the profession needs is a mechanical turn of mind This is

not only broad and wide sympathy, but his capacity to visualize great schemes should be as great as of the best men in any other profession. A great engineer has to be not only a great scientist and mathematician, but also a great economist His inventions are with reference to their utility to society, and as such the economic part of his mind is not one whit less important than the constructive or inventive part of his mind. There may be professions which take things from society, but you take nothing without giving something in return, more directly than any other profession I have no doubt it is firmly established that no country can

engineering profession of the world.

So far as the Punjab is concerned there are great problems which face you and directly affect the economic development of the province. Communications—thereby I mean surface communications—are the problem of the day. They are far too expensive to keep in decent order. The days of the camel and donkey transport are over; and unless aerial communications render surface communications unimportant, you must find the way to make communications in the Punjab less expensive than they are at present

Again on the irrigation side, there is the trouble of waterlogging; how to render your canal and channel beds proof against absorption;

gations and experiments.

There is one point to which I wish to invite your attention. Recently

satisfaction to the people that it has been approved This is not, however, what I had in mind Even after the irrigation schemes are in working order, there is a tendency for a large proportion of the population of the country to be unemploy[illegible] concerned, the country [illegible] for lamps gave place to k[illegible] ed wicks; and now we are at the stage where these are going to be replaced by electric current, wires, bulbs, fuses, etc. Similarly, the camel, ekkas and *gaddas* gave way largely to steam transport and horse-driven conveyances; but these in turn are giving way to "Fords" and "Chevrolets." These emblems of civilization are tending to upset the economics of the Punjab. No doubt there is great pleasure and *prima facie* economic advantage in rapidity of motion; but it is felt in some quarters that these improved facilities of electric and other power may prejudicially affect the economics of the Province and impoverish middle class people It is realised by some that the machinery and accessories used in our lighting, transport, improved water-supply and other adjuncts of civilization are very largely imported. With all the engineering skill assembled in this hall, should they continue to be imported? Should all our engineering skill be employed in government service? Is there [illegible] the people.

Great indeed have been the achievements of the Engineering Congress in the past; but I have not the slightest doubt that greater achievements await it in the future If the admiration and the appreciation of the people can be an incentive to more strenuous efforts, then, members of the Engineering Congress, permit me to assure you on behalf of thousands and thousands of Punjabees of their most sincere admiration and appreciation of your great and abiding work.

[illegible] Besides, under the reforms there were some persons who made strenuous efforts to bring your department and other departments of Government closer to the people than they had ever been, and amongst other services of His Excellency Sir Malcolm Hailey this will be remembered by the people of this Province and by this Congress. Now other departments and the Punjab public know you much better than they did ten years ago. I have not the slightest doubt that most of the suspicions have been dissipated and their appreciation and admiration for you has increased many fold. I consider that in this particular work such little service that I was able to

render has been of some advantage both to your profession and to the Punjab public. I can not reasonably accept the nice things about we that your President said to you. I have no doubt that any body else in my place would have done exactly the same, perhaps more effectively, than I have been able to do. All the same it is a matter of satisfaction for one to feel that the department or profession, with which he was connected, should be, at the time when he is about to leave the reins of office, better understood and better appreciated by the people, whom it serves than it was at the time when he took over the work of his department.

I must not stand between you and your work—time is pressing and I now declare the Congress open.

PAPER No. 133.

CONSTRUCTION PLANT AND METHODS USED ON THE UHL RIVER HYDRO-ELECTRIC PROJECT.

By

COLONEL B. C. BATTYE, R.E., A.I.C.E., A.M.I.E.E., M. Am. Soc. C.E., M. Am. I.E.E.

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THE CONSTRUCTION PLANT OF THE UHL RIVER HYDRO-ELECTRIC PROJECT.

[illegible]
brief [illegible]
taries [illegible]
tude of R. L. 6,100. The flow of the Lamba Dag is taken by a small flume and discharged into the Uhl river tributary above its weir and the combined discharge of both these tributaries screened through a couple of coarse and fine screens for elimination of logs and boulders, through a pair of intake gates into a double decantation chamber, each half containing two chambers in series, designed to remove gravel and coarse sand respectively; the velocity in the second portion will be reduced to 1 foot a second. These decantation chambers during the flood season will operate with a continuous under-scour to ensure the continuous removal of the deposited matter. The outlet of the decantation chambers discharges into a high velocity flume, approximately 200 feet long, ending in the "Blue Pool" stilling pond, from which two 6 feet 3 inch diameter pressure ducts, 2,150 feet long, will convey the water across a nala bed to the upstream end of the upper main rapid. This [illegible]

[illegible]

if required, into an upper emergency storage reservoir. The outlet of the upper stilling pond discharges into an open flume 200 feet long; [illegible]

[illegible]

above mentioned emergency reservoir, and finally the main screened outlet into an 8 feet diameter pressure duct, connecting direct to the main tunnel, for use during the summer months when the water is too dirty to be safely stored in the diurnal reservoir. This 8 feet pressure duct runs under the floor of the diurnal reservoir straight into the tunnel, being controlled by an 8 feet butterfly valve at the entrance to the tunnel itself.

The diurnal storage reservoir 25 feet deep has a capacity of seven million c. ft. and is designed to store 150 cusecs for 12 hours a day, thereby enabling the minimum river discharge to be stored up at night, *i.e.*, during the hours of low demand, so as to provide peak discharges of double this quantity during the following day. This reservoir is provided with an overflow, a scour back into the river, and a screened offtake controlled by an 8 feet diameter butterfly valve leading direct into the above-mentioned pressure duct at its actual entrance into the tunnel.

It will thus be seen that there are two separate methods of supplying the tunnel as follows.—

(a) During the summer months when there is plenty of dirty water, direct from the forebay;

(b) During the winter months when the water is clear but scarce, direct from the diurnal reservoir.

The above describes the arrangements for supplying the tunnel during the first stage, for which the normal winter supply of the river *i.e.*, 150 cusecs, is adequate. For the second and later stages of the project, an average flow of 300 and peak discharge of 600 cusecs will be required To provide this extra quantity, storage during the winter months will be necessary. This storage will be obtained by the construction of a dam, approximately 270 feet high, located in a gorge half a mile downstream of the above mentioned diurnal reservoir. This will create a storage of 46,000 acre feet, which can be filled up during the months of August and September and will increase the winter supply from 150 to 300 continuous cusecs

The conditions of the catchment area do not permit of this storage being maintained during the monsoon period, otherwise there is a risk of the reservoir being silted up in a few years. Arrangements have therefore to be made for bye-passing the dam and discharging the monsoon flow through the bye-pass during the summer months.

The intention is to provide a bye-pass which will only be capable of discharging the maximum floods under the maximum head. This means that during heavy floods, the reservoir will fill up and completely [illegible]

pond might entirely submerge the arrangements for drawing water from the river during the first stage and also during the summer months of the second. It is in order to avoid this that it has been deemed ad- [illegible]

tunnel after the construction of the dam, a valve chamber is being provided about 200 feet from the inlet, accessible (eventually after the dam is built) by a shaft from the surface, and containing an 8 feet diameter butterfly valve in the main tunnel itself designed to withstand the full head due to the height of the dam when closed.

In the second stage during the winter months the tunnel will be supplied from an entirely separate intake located just above the dam, for which a separate adit into the main tunnel will be provided, joining it just beyond the valve chamber. This separate adit is being utilised

at present in the first stage for construction purposes, and also (before the shaft is sunk) for access to the valve chamber.

The tunnel is approximately 14,200 feet long and will be 9 feet 3 inch internal diameter, lined with concrete throughout so as to provide reliable friction conditions and at the same time ensure its being watertight under the comparatively high hydrostatic head to which it will be subjected after completion of the dam in the second stage. The tunnel has two exits. one for scouring purposes only through the construction adit approximately 1,200 feet long, which has been driven in from the Wyer nala from R L. 5,760 so as to reduce the total amount of main drive through the mountain range to 11,100 feet; the second and main exit into the surge shaft, where the tunnel proper ends. It then bifurcates into two 6 feet diameter steel pipes, each concreted up solid in one of two separate pipe tunnels, each 1,200 feet long, emerging at the surface at R. L 5,635.

The surge shaft is 375 feet in depth from the ground surface to the centre line of the tunnel, is 12 feet and 16 feet in finished diameter in the upper and bo [illegible]
main chambe [illegible]
will be of the [illegible]
which a reinf [illegible]
will be provided Above the [illegible] feet level it will be of the simple type, 12 feet in diameter, with a modified contraction, formed by the riser and ports of the Johnson.

At the tunnel exit, the two main pipes each bifurcate again into two steel pipes of 4 fe [illegible] these will be located an automat [illegible] a butterfly isolating valve of [illegible]

During the first stage, two out of the four pipes are being installed and will be located on concrete supports, on the main Shanan spur, [illegible]

The four pipes in their lower halves will be gradually reduced in diameter from 4 feet 7 ins. at the top end to 3 feet 7 ins, just above the power station. The comparatively large diameter of the pipes at the bottom end necessitates their reinforcement by solid-drawn steel bands throughout the bottom half. Each of these pipes is designed to carry 200 cusecs at velocities [illegible]
feet per sec. at the bottor [illegible]
pipe bifurcates into two c [illegible]
100 cusecs. There will thus eventually be [illegible] pipes entering the power

station, each carrying 100 cusecs. Each pipe will supply one single-jet pelton wheel turbine running at 428 r. p. m and driving an alternator of 12,000 kw capacity at 11,000 volts

The power station consists of two parts, the power house proper and the transformer station:—

The power house consists of three buildings:—

(a) The turbine room containing the 8 generators described above, with an annexe for auxiliary equipment.

(b) a control building containing the control room and auxiliary equipment connected therewith

(c) a switch annexe containing the 11,000 volt switchgear controlling the output of the generators.

On a large flat space constructed on the higher ground immediately above the power station, will be located the transformer station, where the output of the generators will be stepped up to a pressure of 132 kv by transformers, and thence transmitted by transmission lines to Lahore and Kalka.

In the first stage of the project, four generating sets only will be installed with two transformers and the accompanying switchgear.

A general idea of the works area is given in drawings numbers one and seven.

For the building of these works a construction project had to be prepared, consisting briefly of the following:—

(1) Housing for both temporary and permanent staff for the construction and eventual operating establishment.

(2) Bridle paths, roads, railways and haulages, connecting up the various levels of work on both sides of the range.

(3) Provision of about 1,200 kw of power and a complete system for the distribution of power; and an automatic telephone system for about 24 subscribers

(4) The provision of the usual construction plant consisting of mechanical excavators, winches, locomotives, rolling stock, cranes, concrete mixers and ordinary tools and plant.

(5) The special equipment required for the driving of the tunnel

These will now be described in detail.

Little time need be spent on the ordinary housing and construction plant, and the bulk of the paper will be devoted to a description of (a) the communications between one portion of the works and the other by means of haulages: (b) the arrangements for the provision of power and its distribution; and finally (c), the special equipment installed

for the driving of the tunnel, which forms the major work now under construction.

All housing was arranged as far as possible to be earthquake-proof and suited to the type of climate involved. During the early stages, for permanent buildings steel frames with hollow brick walls were adopted. This has been replaced later by expanded metal rough-casted outside and plastered inside, with an air space between.

Temporary buildings (roofed with 24 gauge C. G. I.) were constructed on poles fixed in the ground upon which all roof trusses and wall plates were supported. These were calculated to last about three or four years but it is anticipated that some difficulty may be experienced, due [illegible]

[illegible] had to be provided for every man and cooly employed on the works, always including a piped water supply and complete sanitary arrangements. At the upper levels and in the Brot valley, snow is experienced for about three months in a year and on some occasions the quarters have been buried and the occupants have had to be dug out.

The chief features of interest in the construction plant are, an electrically driven one-yard excavator of the Marion type built by Ransomes and Rapier to the former's designs, electric winches, crushing plant and concrete mixers.

The Marion excavator is of that firm's standard design in which the [illegible] btained by means of [illegible] from a motor gene- [illegible] ase induction motor and fitted [illegible] g voltage" or consta [illegible] tually be "stalled" [illegible] moments without d [illegible] and it has given good service under most trying conditions. The only serious replacements that have had to be made are associated with the breakage of the pads when traversing jagged pieces of broken rock, and the replacement of the compressor which had evidently been designed for use at sea level and whose capacity at 4,000 to 6,000 altitude necessitated it runn [illegible] use. [illegible] no fa [illegible] for [illegible] the [illegible] 3,500 cubic feet, [illegible] erial handled is [illegible] a sandy loam alluvium. Boulders up to seven tons in weight are handled by rope slings, slung to the teeth of the bucket. The lowest cost in any one month, (exclusive of interest and depreciation on the machine) was Rs. 34⅓ per thousand cubic feet.

The electrical winches used are of the British Steel Piling Company's standard make and have the following characteristics:—

Size.	Speed of rope.	Size of rope.	Length of rope on drum.	H. P.
ton.	ft.-min.	diam		
1½ ..	150	5/8"	750'	20
2 ..	50	5/8"	2,500'	10
4 ..	50*	7/8"	3,600'	25

*Converted latter to 100 and 50 HP. The 4 ton machines were not standard and were installed later on the Brot haulage; they are equipped with solenoid brakes. The two ton winches have been converted to 150 feet per minute and 25 HP by using the motors removed from the 4 ton winches as explained above.

One of the two ton winches has been used for the sinking of the [illegible]

lost

Two complete rock crushing and sand roll equipments have been installed, one at Brot and the other at the southern adit entrance. These are both Baxter standard machines, containing jaw crusher, conveyor, elevator belt, a large revolving screen, and two sand rolls. Both sand and aggregate of any required grading can be produced. These machines have so far given satisfaction, except for dust trouble for which no adequate solution has yet been found.

A standard specification for concrete for the whole project has been prepared based upon the standards of the American Society for Testing Materials, but with the chapter on proportioning entirely re-written so [illegible] -cement-ratio methods in the [illegible] solved by the use of certain [illegible] for the purpose, consisting [illegible]

Balance scales for weighing out cement with standard conical concrete counter-weights to which lead discs, (marked with the type of concrete) are added as well as smaller lead discs to compensate for each per cent of extra water in the fine aggregate; the amount of this is ascertained daily by means of a hydrometer and checked at intervals in the laboratory. For further particulars see Chapter V of the 3rd edition

of Hydro Electric Branch Specification No 17 This method of proportioning and mixing has been specially designed for Indian conditions, is fool-proof and has proved satisfactory and is now standard throughout the works All mixing is done in either quarter- or half-yard electrical mixers, in connection with each of which is a tank of fixed capacity, the contents of which cannot vary and upon which the proportioning of the whole batch depends, extra cement and aggregate being added as required (using the lead discs referred to above) to balance the extra water in the fine aggregate.

A chart is attached showing the fluctuations and steady improvement in test results of the standard mix used for ordinary reinforced concrete work.

For working the Hill Top Tramway, the Headworks Tramway and the various construction lines associated with the construction of the diurnal re
burning v
railways,
design have been found more convenient than bogies, they can be pushed about by hand and easily replaced after derailment For the tunnel tramways, 10 ton mining type electric locomotives have been used, built to the specification of the Department by the English Electric Company These can be driven either direct from a 200 volt overhead trolley, or by an Edison battery. These machines are of high grade make and are giving excellent service.

The above equipment is backed by a small permanent workshop containing the following equipment.—

1. Portable Electric Arc Welding Plant.
2. Band Saw
3. Saw Gulleting machine.
4. Universal Joiner.
5. Wood turning lathe.
6. 13-inch Redman lathe.
7. 8-inch Turner Hoare lathe.
8. Milling machine.
9. Radial drilling machine.
10. High speed drilling machine.
11. Emery Grinder
12. Grind Stone.
13. Power Hacksaw.
14. Screwing machine.
15. "Oster" light hand screwing machine 0-2.
16. "Oster" light hand screwing machine 2-6.
17. Shafting, hangers, and bearings.
18. Pulleys, counter-shafting, and main belting.
19. Marking-out table.
20. 40 H.P. motor.

21. Hammers, Wrenches, Forces, Tilting furnace, Moulders' tools, Vices, and other workshop equipment.
22. Sheet rolling machine.
23. Angle bending machine
24 Rhodes slitting machine, slits up to ¼" M. S. Plates.

Of the above, the power hacksaw, drilling machines and lathes are naturally those most constantly employed The electric welder, slitting machines, plate rollers, and angle bending machines have all proved particularly useful This workshop is permanent equipment, located on the Shanan siding, level with the power station floor; associated with it is a large permanent store for the housing of spare parts and general stores.

Turning now to road and railway communications: the first thing to be done was the construction of a bridle path from Shanan up to the level of the tunnel adit: thence to Winch Camp at 8,000 feet and from there along the Hill Top Tramway to B's Neck and thence down to Brot This formed the only means of communication on the works during the first two years of construction, prior to the completion of the haulageways.

The railway system is briefly as follows:—

A level 2'-6" gauge siding 1,300 feet long, from the terminus of the Kangra Valley Railway, past the permanent workshop and stores to the site of the power house, terminating at the bottom of the pipeline haulageway at R L 4,141. Thence the metre gauge pipeline haulageway hauls loads up to 15 tons past the tunnel exit at R L 5,635 up to a junction point at R L 5,810 immediately above it This haulageway parallels the pipe line through most of its length and will be used for installing the main penstocks

From the above mentioned junction at R L. 5,810 the 2' 6" adit Tramway runs at a grade of 2·4 per cent. down to the " detonator spur " located in the Wyer Nala on which has been constructed the compressor station serving all the southern tunnel headings. From the detonator spur, the line runs up at a 2·8 per cent grade to the adit entrance, a total length of 9/10th of a mile. This Tramway traverses some very bad ground and necessitated the removal of a large proportion of the hill in one section in order to secure the safety of the formation; many of the sidecuts are 140 feet in height and still give trouble during the monsoon

Returning to the top of the pipeline haulageway at R. L. 5,810, a second metre gauge haulageway of five ton capacity continues up the spur to Winch Camp at about R. L. 8,000, which is the southern terminus of the Hill Top Tramway and contains the winch house, loco shed, storage space, transfer crane and a couple of subordinates quarters.

From this terminus at Winch Camp the 2'-6" Hill Top Tramway has been constructed for 1¾ miles at a compensated five per cent. grade across the south-west face of the hill to B's Neck where it crosses the hill

at R. L. 8,330, and thence continues level for a further 3/8 of a mile to the top of the Brot haulageway at R. L. 8,330

At this terminus of the Hill Top Tramway is located the Brot Haulageway winch house, transformer station, crane and operators' quarters The averag [illegible]
the Brot haulageway [illegible]
upper terminus of the [illegible]
the Uhl river tributary, where a loco shed and transfer crane is located.

From this, the upper terminus of the headworks tramway (known as zero point), the headworks tramway runs for 1 3/8 miles at an average grade of five per cent past the junction of the Lamba Dag tributary, the decantation chambers, crosses over the top of the two pressure ducts, past the west side of the upper emergency reservoir, where a permanent cement store has been located, and thence follows the bank of the main Uhl river to the upper end of the diurnal reservoir where the main Divisional store is located. At this point the line bifurcates into two branches, one running along the outside boundary of the diurnal reservoir to the stone dump and the site of the dam, and the other continuing at a down grade past the crusher plant and compressor station into the *north tunnel heading, with a number of construction sidings* now employed for the excavation of the main diurnal reservoir.

The most interesting feature of these communications is the three haulageways.

The Winch Camp and Pipeline haulageways are both the same type, except that the latter is designed to haul up to 15 ton loads (pipes) as against the normal five ton loads of the Winch Camp and Brot haulages.

The system of haulage adopted is that in which a rope slightly longer than the total length of the track, with a car at either end, makes three (or four) turns over a pair of sheaves, driven through gearing by means of an electric motor, and provided with the following brakes and safety devices :—

A post brake on the motor shaft operated by a weight which is tripped automatically by—

- (*a*) a foot lever on the control platform ;
- (*b*) a mechanical limit trip on the track ;
- (*c*) a 15 per cent. over speed governor on the motor, and
- (*d*) by an electric solenoid when the current fails or by the tripping of the main circuit breaker, which in turn is automatically tripped by—
  - (*i*) a drop in voltage ;
  - (*ii*) an excessive overload, or
  - (*iii*) the movement of the operator off a spring-supported standing plate, which takes the place of the usual dead-man-handle ;
  - (*iv*) by the car striking the limit switch on the track which acts as a back-up to item (*b*) above.

21. Hammers, Wrenches, Forces, Tilting furnace, Moulders' tools, Vices, and other workshop equipment.
22. Sheet rolling machine
23. Angle bending machine
24. Rhodes slitting machine, slits up to $\frac{3}{4}$" M. S Plates.

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From the above mentioned junction at R. L 5,810 the 2' 6" adit Tramway runs at a grade of 2·4 per cent down to the "detonator spur" located in the Wyer Nala on which has been constructed the compressor station serving all the southern tunnel headings. From the detonator spur, the line runs up at a 2 8 per cent. grade to the adit entrance, a total length of 9/10th of a mile. This Tramway traverses some very bad ground and necessitated the removal of a large proportion of the hill in one section in order to secure the safety of the formation; many of the sidecuts are 140 feet in height and still give trouble during the monsoon.

Returning to the top of the pipeline haulageway at R. L. 5,810, a second metre gauge haulageway of five ton capacity continues up the spur [illegible]

From this terminus at Winch Camp the 2'-6" Hill Top Tramway has been constructed for $1\frac{1}{2}$ miles at a compensated five per cent. grade across the south-west face of the hill to B's Neck where it crosses the hill

so far been very successful; no serious slips have occurred on any of the haulages and very little damage has been done during the last three monsoons

The steep slopes upon which the track has been built preclude the possibility of using ordinary broken metal, the stones tend to mount onto the sleepers and damage the rope. The track therefore has been pitched with hammer dressed stone throughout its length, the pitching being built up level with the top of the sleepers for the full width of the sleepers, outside which are located the two stone pitched drains already referred to This system of packing and pitching has proved quite satisfactory from the point of view of erosion from rainfall, but is troublesome in connection with the maintenance of track levels. The track tends to settle after a few weeks' use and the pitching has to be removed before the track can be packed again As the life of the deodar sleepers is also limited, it is open to discussion whether the more permanent method of construction standard in Switzerland would not have proved cheaper in the long run This consists of a solid masonry [illegible]

upkeep and renewals.

In designing haulages of this type several important points have to be provided for—

(i) First of all, all [illegible] to be made at convexities [illegible] ep the rope on the rollers [illegible] in mind in [illegible]

(ii) The grade of the haulage in each section has to be so adjusted as to ensure that the ratio of the tension in the two ropes as they enter and leave the three or four-grooved sheaves, after providing for the loads on the cars, the cars themselves, the weight of the rope and the friction of the ropes on the rollers, does not exceed 3·7 for three wraps, and 6·6 for four. This allows a factor of safety of 1·5 as the rope is likely to slip on the sheaves if the ratio exceeds five with three sheaves or ten with four. This necessitates many adjustments of the profile (often completely upsetting any attempt at balancing cuttings and embankments) before the final profile can be decided. To enable this to be done, a diagram and calculation table has to be prepared, on which the load on the two ropes entering and leaving the drum are calculated for every position of

There is also a hand wheel which enables the gear to be locked at any time ; and finally electric regenerative braking : this is normal standard operation whenever the down load exceeds the upload, which usually takes place with balanced loads whenever the cars have passed the half-way point, (due to the unbalanced weight of the rope).

It was originally hoped to provide each car with the usual safety device to grip the head of the rail in the event of a failure of the rope. This equipment not only greatly increased the cost of the cars themselves (partly owing to the cost of the equipment and partly owing to the fact that they had to be made much heavier and sturdier to withstand the strain) but necessitated the use of a special type of patented rail head which nearly doubled the cost of the track. The cars are all however provided with a screw-on rail-head grip which is capable of holding a loaded car to the track on the steepest trade in order to prevent it shifting position due to the elasticity of the rope when being loaded or unloading at any intermediate point. This device is an essential when unloading Penstock Pipes for erection.

Particulars of the ropes actually supplied will be found in Appendix 8.

These ropes run on soft cast iron rollers and are prevented from rising more than 12 feet above the track by overhead guide frames to which similar hinged rollers are fitted.

The cars are of an ordinary four-wheel type with long wheel base. The wheels on each car on one side are double flanged and those on the other side flangeless, the flanged wheels on the two cars being on opposite sides. This enables the cars to be operated on a single track except at the passing place, where they automatically pass on to their correct tracks without points and without the necessity of attendance.

The tracks are the ordinary standard metre-gauge using 41½ lb. rails and deodar wooden sleepers. The track is anchored to a carefully designed concrete anchor located at every 90 feet. These anchors are designed to take not only the thrust of the rollers and track under varying temperature conditions, but also that of a fully loaded car [illegible] e upper [illegible] of rail [illegible] taking [illegible]

Owing to the distance apart of the anchors care had to be taken tc ensure [illegible] upon [illegible] suppl[illegible]

Considerable attention has been paid to the drainage of the tracks so as to ensure the removal of all rain water from the track at intervals not exceeding about 100 yards The drains which are fully pitched with stone on both sides and bottom, are carried away well over the watershed on either side so as to ensure against any possibility of the water returning to the track at a lower level. The drainage arrangements have

so far been very successful; no serious slips have occurred on any of the haulages and very little damage has been done during the last three monsoons

The steep [illegible] possibility of u[illegible] onto the sleepe[illegible] pitched with hammer dressed stone throughout its length, the pitching being built up level with the top of the sleepers for the full width of the sleepers, outside which are located the two stone pitched drains already referred to This system of packing and pitching has proved quite satisfactory from the point of view of erosion from rainfall, but is troublesome in connection with the maintenance of track levels. The track tends to settle after a few weeks' use and the pitching has to be removed before the track can be packed again. As the life of the deodar sleepers is also limited, it is open to discussion whether the more permanent method of construction standard in Switzerland would not have proved cheaper in the long run This consists of a solid masonry wall under each rail connected by light steel ties at intervals. Their maintenance is practically nil and there are no sleeper renewals. Our system of construction, though cheaper in first cost, doubles maintenance, upkeep and renewals

In designing haulages of this type several important points have to be provided for—

(*i*) First of all, all changes of direction have obviously to be made at convexities, otherwise it is impossible to keep the rope on the rollers This has to be carefully borne in mind in [illegible]

to the haulageway down to Brot on the northern side of the range, in fact the one finally selected was the only spur really suitable for the location of a haulageway and was only finally settled upon after three years' investigations.

(*ii*) The grade of the haulage in each section has to be so adjusted as to ensure that the ratio of the tension in the two ropes as they enter and leave the three or four-grooved sheaves, after providing for the loads on the cars, the cars themselves, *the weight of the rope and the friction of the ropes on the* rollers, does not exceed 3·7 for three wraps, and 6 6 for four. This allows a factor of safety of 1·5 as the rope is likely to slip [illegible] if the ratio exceeds five with three [illegible]

[illegible]

To enable this to be done, a diagram and calculatio[illegible] to be prepared, on which the load on the two ro[illegible] and leaving the drum are calculated for every [illegible]

both cars A sample of this diagram is given in Appendix I. This difficulty can under certain circumstances be got over by the employment of a ballast car, which is picked up by the upgoing car when nearing the upper end of the incline thereby balancing the additional weight of the rope of the lower car. This arrangement has been adopted with success on the Winch Camp haulageway, which otherwise would not have been operable.

(*iii*) A third condition, which must not be overlooked, is the necessity for maintaining the grade at not less than about 11 per cent, depending upon the position of the grade in question on th incline, and the relative stresses in the two ropes under the worst conditions. If this grade is not maintained, a lightly loaded down-going car may not be able to maintain its movement against the friction of its own rope.

(*iv*) Another point of importance is the possibility of a heavily stressed rope lifting up a lightly loaded car off its track and derailing it, when the latter is located at the lower end of a concavity on a comparatively flat grade near the top of the incline, the rope in question being heavily stressed at the time owing to its being attached to a heavily loaded car located on a steep grade near the bottom of the incline.

This danger arises because, in such conditions, the heavily stressed rope attached to the lower car has to pass under and be weighted down by, the upper lightly loaded car This introduces further complications in the adjustment of the profile which in some conditions makes it impossible to operate certain profiles.

In the construction of the Pipeline haulageway, which has a comparatively straight track at an even grade, these restrictions did not affect the profile appreciably ; except that they necessitated the provision [illegible]

These considerations became of governing importance in the design of the Winch Camp haulageway, which has to follow many curves both vertical and horizontal, in order to conform as nearly as possible to the surface of the spur before reaching Winch Camp. This in turn necessitated some very costly cuttings and banks which otherwise might have been avoided if a different system of haulage had been installed. Even

with these adjustments of the profile, a ballast car was found necessary and is in regular operation The use of a ballast car necessitates a signalling arrangement when approaching the ballast car so as to slow down the car before buffing. The following horizontal and vertical curve radii were adopted.—

Pipeline 500 feet radius for both horizontal and vertical curves.

Winch Camp horizontal 500 feet, vertical 250, 500 and 1,000 feet

When we came to design the Brot haulageway, where the country is much steeper, ending in a very steep stretch near the bottom end (incidentally one of the most difficult conditions to cope with, and one very common in the Himalayas), the conditions became even more formidable than those on the Winch Camp route It was therefore decided

length of the cable was found to be excessive, moreover such a drum could not be transported to Winch Camp until the completion of the pipeline haulageway. A further consideration as to the type of winch to be installed was connected with the necessity of providing temporary winches which could be installed at intervals on the two southern haulages for their construction. These haulages were constructed as follows:—

Having excavated the formation, a hand winch was then transported in pieces and installed about 100 yards up hill. This was used for hauling up the track equipment until the track was installed up to the winch.

sufficient

light 1½ t

1,000 feet, being hauled up in pieces by the hand winch. When two or three lengths of "electric haul" had been installed, these were then replaced by a larger electric winch of four ton capacity. These large electric winches then operated the haulageways for several months during the installation of the permanent winches and winch houses at the top. This arrangement necessitated the purchase of at least two four ton winches, capable of carrying about 3,000 feet of rope.

This fact, combined with the difficulty of transporting a larger drum to Winch Camp, led us to economise on the Brot haulage by the installation of two four ton drum winches, one at the top and one half way down, which could, in the meantime, be used for the construction of the other haulages. The employment of two such drum winches enabled us to adopt a comparatively cheap formation, practically following the surface of the ground, thereby saving a large sum not only on the formation but also on the winches. This system, however, necessitates the maintenance of two winch houses and two operating staffs and the transfer of the car from one rope to the other half way down. This immensely slows down the speed of operation and reduces the capacity

of the haulage This system however is satisfactory for the first stage of th project but may have to be supplemented for subsequent stages *i.e.*, when the times comes for the construction of the dam. As however most of the loads will then be Portland Cement down hill, it may be

therm

(For

and

long

wood from the oak

" travelling rope "

brickfield. These

operated steadily for about two years and gave satisfaction)

The construction of the Hill Top Tramway presented most of the difficulties usually met with on hill roads, but in a somewhat exaggerated form. About one-third of the formation had to be cut out of vertical granite cliffs, involving cuttings up to 150 feet in height many of which had to be started from cradles. This work was carried on continuously throughout the winter by a gang of 50 specially clothed men using an

and was designed to enable the engine to be replaced by an electric motor when power became available. The conversion to electric drive was effected as soon as the Dhelu plant was put into operation, and the machine has since given good service as an electrically driven compressor

The above described haulage system has now been completed and in operation a little over a year and it is possible to give some figures of capital and operating cost · see Appendices 2 and 3 The figures quoted in Appendix 3 are based upon continuous operation during the hours of daylight, using electrically operated transfer cranes at top and bottom terminals.

POWER SUPPLY.

Turning now to the arrangements for power ; this is obtained from two water driven stations, one located at Dhelu on the Gugli Khad three miles from Shanan on the southern face of the range, and another in the Brot valley on the banks of the Uhl and using the waters of the Lamba Dug. The two stations are linked by means of an 11,000 volt transmission line which supplies 9 small outdoor substations located at the chief load centres on the works.

The Dhelu station is Pelton wheel driven consuming up to 24 cusecs on a head of 740 feet. The water is collected from two rain-fed nalas and delivered to a small forebay through a flume designed for 21 cusecs. The flume is of composite design consisting of cement plastered lime concrete where the ground is suitable, connected by short lengths of "armco" on timber trestles. The station is supplied by one 18" welded steel pipe with muff joints and contains two

Pelton wheel driven 3,300 volt 600 kva, 750 r. p m. 3-phase alternators of standard design.

The Thuji plant contains one 500 kw Francis turbine driven 400 volt, 600 kva, 750 r. p. m. 3-phase alternator operating under a head of 98 to 198 feet and consuming 70 cusecs conveyed by an open masonry flume 4 100 feet long from a headworks of rather special design located on the Lamba Dag.

The pressure on both these stations is stepped up by out-door transformer stations of a design similar to that adopted for substations. For the transmission lines No. 5 copper wire supported on wooden H poles has been adopted as standard, except on 4 long spans on the south-west face of the hill at an altitude of 8,000 feet between Winch Camp and B's Neck, where spans of 2,500 feet have been employed using 7/·104" [illegible]

B's Neck, the highest point of the system, the insulation has been doubled and a set of oxide film arresters has been installed. The system has operated remarkably satisfactorily for the last 2 years, the chief failures being due to sheets of corrugated iron being blown off coolies quarters into the substation wiring.

Space does not permit of a more detailed description of the system but the following points may be instructive:—

The gaugings made in 1922 for the supply of the Dhelu power station gave two figures, one amounting to 12 cusecs based on the flow of the river with as many Kuhls as possible shut off, and one amounting to 19 based on the observed flows of all the Kuhls added together. An average of 15 cusecs was therefore, adopted for the purpose and arrangements made for a oil standby set. Subsequent experience indicated [illegible] gure [illegible] for [illegible] ade) [illegible] of a [illegible] two stations operate in parallel satisfactorily and the sub-division of plant into a station on each side of the hill has proved invaluable in maintaining continuity of supply.

[illegible]

overlooked in selecting the size from the maker's catalogue. The adoption of Armco has rendered it impossible to increase the capacity of the flume after completion With this exception, the plant has given good service.

The Thuji flume traverses very bad ground and should have been covered for longer lengths than was done, this resulted in several wash-outs during the first monsoon till it was covered. The special type of headworks was on more than one occasion completely [illegible]

danger of suddenly emptying the forebay and throwing off its load without warning This is being overcome by the installation of a load [illegible]

In order to prevent the chute wearing out under the high velocities at which it operates, it is necessary to limit the discharge in the flume to that actually required at different times of the day. With the load limiter installed, it will be possible to adjust the discharge of the flume to the exact amount required and reduce the discharge down the chute to a negligible quantity This method of operating the two stations in parallel, *i.e.*, with the Thuji plant more or less permanently fully loaded, is rendered difficult by the fact that the Thuji governor is a more modern and sensitive governor than those at Dhelu. the result is that the Thuji machine tends both to pick up and discard load in preference to those at Dhelu This will necessitate the continual reloading of the Thuji machine by the operator after each reduction of load if the chute is to be kept empty. It is hoped to get over this difficulty by "setting" the Thuji governor above its synchronous speed but until the load limit device has been installed this cannot be tested.

To economise in operation, arrangements were made to enable the Thuji station to be operated by remote control from the compressor station about half a mile away where a permanent operating staff has to be employed in any case; arrangements are now being made to add a load limiter and thermostat on the bearings; experience has shown that without these it is inexpedient to leave the plant unattended

The pipeline of the Thuji plant is of rivetted steel plate, manufactured in Calcutta, and has given entire satisfaction.

Particulars of the capital cost of these two plants and also the annual cost of operation and resulting cost of power will be found in Appendices 4 and 7.

Tunnel plant.

[illegible] ient has been installed [illegible] on the south side ad- [illegible] tunnelling and sinking [illegible]

driven in one main heading
200 feet adit approximately
the Wyer Nala in a north-
rn end of the tunnel 10,500
feet from the northern portal and approximately 3,200 feet from the surge shaft. From the head of this adit two main headings are being driven, one towards Brot and the other towards the surge shaft. Simultaneously two pipe tunnels, each 1,200 feet long, are being driven in from the tunnel exit to the surge shaft, and a surge shaft, 380 feet deep, sunk from the surface.

A compressor
two and three 600 c
each compressor
of 120 B H P. at 363 r. p m. supplied at 400 volts, 3-phase from the adjacent out-door substation To each compressor is connected a receiver to store 160 c. ft of air at 120 lbs./square inch from which a 6" victaulic joint steel delivery pipe runs up to the heading, with (on the south face) a tee connection for the supply of the pipe tunnels and surge shaft where another receiver is located, from which the supply is continued down the pipeline, serving the power station and workshop area. When the two headings meet there will be five miles of compressed air piping installed guaranteeing a supply of air at 100 lbs. per square inch at practically every point on the works. This system has so far given good service

gauge respectively when running at 1,500 r. p. m. They can exhaust 6,000 c. ft. of air per minute at 40½" and 65½" water gauge respectively, when run at 3,000 r. p. m Both motor fans are provided with roller bearings and require 210 horsepower at full speed but only 39 B. H. P. at ·62 power factor at low speed. One blower alone is now being used during the early stages when the heading is short. As the heading lengthens, the other blower will be used and eventually both will be run in series. The two blowers cannot be operated in parallel owing to their different characteristics, which tends to cause surging and resulting loss of efficiency. The suction and delivery pipes are intercor
reversec
immedi
to sup
heading
capable
at 3,00
similar
sent b

... design, and are not reversible.
16" diameter sheet steel duct.
...hese manufactured in India and
it was found more satisfactory to manufacture them locally of 1/8th inch thick steel sheeting welded and built up in the Shanan workshops. These latter, manufactured locally, have given entire satisfaction and are being used by degrees to replace the rivetted pipes of Calcutta manufacture which have never given satisfaction

For driving the main headings light hammer drifters have been standardised These are of the Ingersoll-Rand N-72 and 74 pattern capable of giving 1,500 to 1,800 strokes per minute and driving a 1½" hole in granite, 8½" deep in a minute. To enable the drills to be mounted and dismounted rapidly, a drill carriage of the Stearns-Roger type, (as found so useful in the Moffat tunnel) was obtained for each heading. These carriages enable four drifters to be run up to the heading and put into operation simultaneously, and are provided with air and water manifolds so that only one main connection has to be made for each service. For sinking, surface work, and driving in soft rock, medium weight hand hammer drills of the Consolidated Pneumatic Company's C. P -5 pattern have been standardised and have given good service.

During the early stages several cases of miner's pthisis developed due to the use of dry drills of the light type purchased for use above ground. When the wet drills were first put into operation, difficulty was experien...
tion. This ...
ments which ...
was originally ...
ence shows that progress cannot be assured with less than 100 per cent. spare drills; this then enables every drill to be entirely overhauled every seven days The driving of the main headings has not yet reached the granite core of the hill and most of the driving has been in soft to medium mica schist, so that few opportunities have existed for a satisfactory try out of the heavy drifters, in fact some 80 per cent of the driving already done has been with hand hammer drills Experience shows that in this country Indian labour prefers the use of hand hammer drills, in fact it is difficult to procure drill runners with any experience in the use of the drifters. These machines are heavy to lift about and handle and it is for this reason that the carriages were purchased. There is undoubtedly a prejudice against the heavier drills and disciplinary measures have at times been resorted to to enforce their use whenever ...

machine (described below) to pass the carriage, necessitating the partial ... by defeating the main
... ain modifications have
... experience of driving

in the hard gneiss, it is impossible to express a reliable opinion on the use of these carriages.

Each heading is served by a 50 lb/yd 2′ 6″ gauge standard railway track. With this equipment derailments seldom occur, but the labour involved in connection with the dismantlement and re-erection of the turn-outs on the double track near the heading caused serious delays in progress This difficulty has been overcome by using a 20 lb. turn-out and siding laid on the top of the 50 lb. with a pair of ramps.

[illegible] mate.

All rolling stock used on this tramway, including the mucking machine, electric loco and tip trucks, have to pass through a four feet square loading gauge in order to enable them to traverse the inside of the concrete centring car. One yard tip trucks of special design had therefore, to be made for this service Several minor difficulties were experienced with the design supplied; these defects have now been rectified by modifications made at site, the most important of these being:—

(*a*) The centre of gravity of the tub as originally received was too low. This has necessitated the lowering of the trunnion on each side of the tub to raise the centre of gravity to enable the tub to be tipped by one man.

(*b*) The axle box straps were of too small section originally, and moreover were only secured by one bolt at either end. It was necessary to put in stronger straps and to secure them by two bolts at each end instead of one.

(*c*) The truck-bodies as delivered to us were carried on the axle box by springs These springs fatigued and broke, and it was necessary to remove them altogether.

(*d*) Solid bar coupling made from loco to first truck.

(*e*) Coupling pin box on tubs cut away on each side.
(Above are to avoid derailments round sharp 55 feet radius curves.)

(*f*) Angle iron at the back of coupling pin box cut away so that links forced back when trucks are being pushed do not jam

(*g*) One coupling link (the forward one) fixed to truck by putting a cross peg in the coupling so that latter can only be taken out by a fitter. (This ensures that link is always on the tub and has not to be hunted for.)

Tip trucks are removed and dumped in rakes of 12 at a time by the electric loco which has so far operated on its battery in the tunnel headings. As the lining is completed a semi-permanent trolley will be

[illegible]

Electric firing has been standardised throughout on all main headings. The cut holes are fired instantaneously and the inner and outer rings in two stages of delay, for which special delay action electric detonators have been imported. These are all fired simultaneously but the delay detonators have short lengths of time fuse which take 5 and 10 seconds to burn before firing the detonator. The 10 second fuses are not very reliable Power for firing is taken from the lighting main by a firing transformer reducing the pressure to 110 volts. This transformer is located about a thousand feet from the heading and moved on as the heading proceeds; the firing switch is kept under lock and key. The disadvantage of this method is that it is impossible to know when a misfire has occurred and on one occasion due to some bad explosive a charge was drilled through and blew up the whole drilling crew This has been the only serious accident on the works to date and was traceable to deteriorated gelignite, imported direct from England and held in stock on the works for two years before use.

As the governing factor in all [illegible] remove spoil after a blast, particular [illegible] It was therefore decided to import [illegible] type which had been found so successful in the driving of the Catskill, Schandaken, and Hetch Hetchy tunnels. This machine consists of a shovel of about ¼ yard capacity, operated by levers and cams and mount- [illegible] m in front of the carriage. It [illegible] belt which in turn delivers to [illegible] ch again discharges into the tip truck located at the back end of the machine. The machine is electrically driven through clutches from one 3-phase induction motor supplied by a cable on a reel. The designs originally supplied were quite satisfactory until water was met with, when both the motor and electric equipment began to deteriorate. The conditions under which the [illegible] been provided with complete water-tight equipment throughout and are of an improved pattern.

In order to enable any one machine to be used on either of the two headings driven from the adit, it was of course necessary to reverse the machine. This cannot be done on a turntable owing to its length and necessitated the construction of a triangle outside the compressor

station. Taking into consideration the appalling conditions under which the machines have worked in our wet and dangerous tunnels, the ser- [illegible] h both labour and [illegible]

For supplying power for the mucking machines, pumps, electric light, charge firing, and the loco trolley, four electric power services have been installed, one 3-phase 400 volt cable for lighting and firing and a 200 volt trolley for the locomotive. Each tunnel is also provided with a 2" pipe for water supply, and the northern heading with a 6" steel pipe for the drainage pump delivery. The erection, maintenance, dismantlement for lining and semi-replacement after lining, has presented one of the greatest problems in the project. The space taken up by all these services in the unlined heading is in any case considerable, and the space available is still less inside the finished lining; but in the centring car itself, where the space is even more restricted, the difficulty of finding room for all these services has necessitated the restriction of all rolling stock to a four feet square loading gauge. The arrangements finally adopted are shown on plates Nos. 1 and 2. For these reasons the very greatest care had to be exerted to ensure the services being properly and neatly erected in the positions assigned to them.

For the maintenance of plant, equipment, timbering, and the reconditioning of drill steel and repairing of drills, each heading is provided with a large smithy equipped with an Ingersoll-Rand forging machine and a furnace, the latter being charcoal and oil fired on the north and south faces respectively. At the north face, a small temporary workshop has been added to enable immediate minor repairs to be carried out at site. The two southern headings are self-draining, so the question of pumping has not arisen In the north heading however, a semi-permanent pumping station had to be installed at the tunnel entrance to clear the water delivered by other pumps from the heading as well as the local *drainage in the tunnel entrance ramp and the surrounding area.* To reduce this latter to the minimum, two catch-water drains have been constructed on the hill sides above, and a third draining the hill below, and discharging in a flume across the railway cutting leading into the tunnel. This has reduced the amount of the drainage water to that in the actual heading itself plus the seepage and rainfall on an [illegible] station contains one 4" [illegible]

The seepage [illegible]
of 2 small 2" [illegible]
two four-inch pumps are kept in reserve. These pumps are all direct-coupled motor driven, on a self-contained bed plate, and can be dismantled and shifted without difficulty. Even with this comparatively small flow and the two 2" pumps referred to, the difficulties of water accu- [illegible]

adjust the floor levels before proceeding. The effect of this alteration in procedure was immediate and practically doubled the weekly progress; it is now standard practice on this heading. The following maximum daily, weekly and monthly rates have so far been attained on the northern heading where the conditions have been most favourable.—

(*i*) Maximum in one day (November 13th, 1929), 13 feet.

(*ii*) Maximum in one week (ending August 17th, 1929), 62 feet.

(*iii*) Maximum in one month, (August 1929), 209 feet.

As the tunnel, when completed, will be subjected to considerable [illegible]

render it out of the question to leave any timber or organic matter between the lining and the rock. Where, therefore, the rock is so bad as to make it impossible to remove timbering before lining operations are started, steel frames of special design have been inserted in place of timber, backed with reinforced pre-cast concrete slabs in place of slab- [illegible]

bad as to necessitate continuous heavy timbering, as has occurred in the main southern heading at R. D. 530. Under these conditions the steel frames are too light, and once they get bent or out of shape it is [illegible]

made to secure high pressure grouting pumps capable of forcing grout into the rock fissures to a considerable depth under pressures rising to 600 lbs. per square inch. This system practically converts fissured rock into a solid conglomerate for a depth of 50 to 60 feet all round the tunnel and is the only known method of rendering such rock impervious under hydraulic pressure.

The major problem in connection with the tunnel is associated with the arrangements for driving and lining simultaneously. The finished diameter of 9'3" is about the minimum that it is possible to drive and line simultaneously. The modern equipment necessary for rapid driving and the high standard of work needed for the heavy internal hydro-static pressures, is so complicated and elaborate that even with this diameter the problem becomes extremely difficult of solution. The following

is a brief sketch of the arrangements so far projected and completed for the lining. The system herein described was worked out in detail two years ago and forms the subject of a "Technical Memo," upon which the purchase of the equipment and the methods of driving and lining were based. Up to date no serious modifications of the system have had to be adopted but as it has not been put wholly into effect to date, it is too early to judge of its complete suitability.

No concreting is permissible within 1,000 feet of the heading. When the heading has proceeded for 1,000 feet clear straight, a series of 8" rolled steel joists are laid across, three feet apart extending for a length of 576 feet. Upon the frame a double track is laid at a level

below the invert. This is then concreted up along with a corresponding length of invert. As soon as the front 80 feet length of this has set,

this car there is then a single 2'-6" track continuous with that already

When this has set, the joists over the new length of invert are shifted forward another 40 feet, the concreting car collapsed and shifted forward 40 feet and the process of laying and concreting repeated. For these

laying and shifting of
problem is associated
re-erection for a weel
For this purpose each
forming part of and

cables etc., through the car before starting to concrete.

Concrete will be proportioned and despatched dry from the depot at the tunnel entrance in concrete dump cars. It will be wet mixed in a quart[illegible] for
it on th[illegible]; the
actual [illegible] At

the time of writing, the equipment is being installed for the first time in the northern heading: it may be possible to give the results of practical experience when reading the paper.

For the disposal of the drain water while laying arrangements are being made to instal a precast concrete drain pipe in a channel cut in the rock below and outside the lining. This will be laid in 40 feet lengths; at the end of each a precast concrete man or hand hole will be inserted, into which weepers will discharge during the process of laying and which will afterwards be used for plugging the drain pipe at every 40 feet interval with concrete and grout, after the lining has set and is therefore capable of taking the ground water pressure.

In places where the rock is not strong enough to take the internal hydro-static pressure of the tunnel, when transmitted to it through the lining, the inside of the lining will be faced with a mantle of reinforced gunnite 6" thick, capable of taking the full hydro-static pressure of the tunnel without support from the surrounding rock. The rings of reinforcing bars for this mantle will be jointed by arc welding at site [illegible]

experience of this type of work elsewhere. These contractors will supply their own cement guns and welding equipment, particulars of which are not at the present moment available.

[illegible]

This will enable grout to be forced into the rock and into the small spaces behind the lining up to pressures of 300 lbs. per square inch. This machine has not yet been put into operation and no operating experience can therefore yet be quoted.

Further particulars of costs, horsepower etc., will be found in the appendices.

My grateful thanks are due to Captain Kenyon, Mr. Bruford, and Captain Guthrie for the assistance they have given me in providing the necessary information and data quoted in the paper, and to Mr. Heath for the interesting landscape sketch.

LIST OF APPENDICES TO ACCOMPANY COLONEL BATTYE'S PAPER FOR THE PUNJAB P. W. D. ENG. CONGRESS.

Appendix 1. Rope tension diagram and calculations.

" 2. Capital cost of haulageways.

" 3. Operating cost of haulageways.

" 4. Capital cost of power plants.

" 5. Cost of different types of plant and equipment.

" 6. Horsepower of various types of plant.

" 7. Operating cost of power plants.

" 8. Particulars of haulageway ropes.

" 9. Particulars of electric locomotive.

[illegible] st time in [illegible] practical

For the disposal of the drain water while laying arrangements are being made to instal a precast concrete drain pipe in a channel cut in the rock below and outside the lining. This will be laid in 40 feet lengths; at the end of each a precast concrete man or hand hole will be inserted, into which weepers will discharge during the process of laying and which will afterwards be used for plugging the drain pipe at every 40 feet interval with concrete and grout, after the lining has set and is therefore capable of taking the ground water pressure.

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For grouting up the rock and tunnel lining a standard high pressure Cannif grouting plant is being purchased, in connection with which a motor driven high pressure Booster compressor has been purchased. This will enable grout to be forced into the rock and into the small spaces behind the lining up to pressures of 300 lbs. per square inch. This machine has not yet been put into operation and no operating experience can therefore yet be quoted.

Further particulars of costs, horsepower etc., will be found in the appendices.

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APPENDIX I.

METHODS OF CALCULATING ROPE TENSION AND MAXIMUM PERMISSIBLE RATIO.

The *maximum permissible ratio of* T *to* t *is* expressed by the following formulla :—

$$\left(\frac{T}{t} = e^{U_s \phi_c}\right)$$

Where e = Base of natural logs :

U_s = *Friction coefficient of rope to sheave.*

ϕ_c = Total radians of contact between rope and sheave.

Slip may occur at about U_s = ·10.

For 3 and 4 wraps of the rope round the sheave $\phi c = 930°$ and 1320° *i.e.,* 16·23 and 23 radians respectively.

The limiting value of $\frac{T}{t}$ then is :—

$e^{1·62}$ = 5·07 for 3 wraps.

$e^{2·3}$ = 10·0 for 4 wraps.

The maximum working figures for $\frac{T}{t}$ actually adopted by us are :—

Pipe Line, 3·67, where there are 3 wraps.

Winch Camp, 6·55, with 4 wraps and a ballast car as well.

The rope tensions (T and t) are found as follows :—

The rope tension at the winch with car at any point X of the rope s the sum of the following 5 items :—

(1) Stress due to load of car on slope at point X .. = $W_c \sin \theta$.

(2) Rolling friction of car on track at 25 lbs per ton.. = $\frac{25}{2240}$ xΣsin Θ.

(3) Load due to the weight of the rope from the top of point X .. = $W_r \ \Sigma L \times \sin\theta$.

(4) Friction of the rollers due to the weight of the rope. = $U_r \ W_r \ \Sigma L \times \cos\theta$.

(5) Friction of the rollers due to the stress of the rope on curves. = $U_r \ T_m \ \phi_c$.

Where T_m=items 1+2+ the mean of 3, 4 and 5, in that length, *i.e.*

T_m = items $1 + 2 + \frac{3+4+5}{3}$.

and where ϕ = Angle of slope.

W_c = Weight of loaded car.

W_r = Weight of rope per foot run.

ΣL = Total length of rope from top to the point X.

U_r = Coefficient of friction of rollers, usually taken as ·0315.

ϕ_c = Total curvature of rope (both vertical and horizontal) on rollers, added up from top to point X in radians.

Attached is a sample table showing how the rope tensions are conveniently calculated.

Owing to the low speed at which these haulages operate, (see table below) the starting acceleration is in any case very small. This is still further reduced by the effect resulting from the gradual tightening up of the rope on concavities which acts like a spring and brings stress onto the rope and winch very gradually. The following further particulars of the pipeline and winch camp haulages are of interest :—

Particulars.	Pipeline.	Winch Camp.
1. Speed	141′ per min.	219′ per min.
2. Time of trip	35′ mins.	30 mins.
3. Horsepower	106	107
4. Diameter of sheaves	9·85′	8·2
5. Net weight of car	4 tons	3·7 tons.
6. Net load	15·2 ,,	5·1 ,,
7. Gross load	19 2 ,,	8·8 ,,
8. Max. force on circumference of driving sheaves ignoring acceleration	9·7 ,,	5·7 ,,

1	2	3	4	5	6	7	8	9	10	11
	[illegible]	[illegible]	T=(2)+(3).	W Σ[illegible]	U_r W Σ L [illegible]	T_m=(4)+(5)+(6)[illegible] / 2	Σ ϕ_c.*	U_r $T_m \Sigma \phi_c$.	T=(4)+(5)+(6)+(9).	Remarks.
Top	..	.	.	0 000	0 000	2 269	0 0	0 000	2 269	
1/2	2 198	0 071	2 269	0 082	0 008	2 316/ 2 983	2 9	·004/ 005	2 303/ 3 030	
2/3	2 864	0 071	2 935	0·344	0 026	3 144/ 3 720	27 7	048/ 057	3 353/ 3 934	
3/4	3·439	0 068	3 507	0 490	0 034	3 810/ 1·644	39 7	083/ ·036	4·114/ 1 924	
4/5 etc.	1 287	0 077	1 364	0 517	0·039	1 667/ 2·898	54 3	·050/ 068	1 970/ 3·210	

*Includes horizontal angles.

APPENDIX 2.

Particulars of Haulageway Costs.

Item No.	Particulars.	Pipeline			Winch Camp.			Brot.		
		Data.	Cost.	Rate.	Data.	Cost.	Rate.	Data.	Cost.	Rate.
Col.	1	2	3	4	5	6	7	8	9	10
1	Winch machinery and foundations, cars buildings, cranes and terminal equipment.	Net load in tons =15·2.	Rs 1,97,000	Rs 12,950 per ton.	5·0 tons.	Rs. 1,37,900	Rs. 27,580	40 tons.	Rs. 1,01,900	Rs. 25,475
2	Track, formation, drainage and telephone lines.	Length in feet =4,963′	1,82,500	Rs. 36·75 ft.	6,476 ft.	1,97,400	30 5	5,563 ft.	1,14,100	Rs. 20 5
3	Ropes, Rollers and Guide Frames.	Ditto.	50,600	10 2 ft	6,476 ft	51,900	8 0	5,563 ft	32,200	Rs. 5·8
4	Total capital cost of whole.	75,500 ft. tons.	4,30,100	Rs. 5 7 ft. ton.	32,380 ft. tons.	3,87,200	Rs. 11·9 ft. ton.	22,252 ft. tons.	2,48,200	Rs. 11·5 ft. ton.

APPENDIX 3.

Particulars of haulageway operating cost.

Item No.	Particulars.	Annual expenditure for all 3 haulageways lumped.	REMARKS.
Col.	1	2	3
		Rs.	
1	Operating Establishment ..	12,000	
2	Loading and unloading of goods at terminal stations	9,500	
3	Materials for maintenance of machinery	3,100	
4	Track maintenance establishment ..	11,900	
5	Materials for track maintenance ..	250	
6	Total of operating and maintenance	36,750	

APPENDIX 4.

Capital cost of power plants.

Item No	Particulars	Dhelu. Cost Rs	Dhelu. Cost/Kw installed	Thuji Cost Rs	Thuji Cost/Kw installed	Remarks.
Col.	1	2	3	4	5	6
1	Kws installed	900 Kw		480 Kw		
		Rs	Rs	Rs	Rs	
2	Headworks, flume and forebay	1,64,005	182	1,47,492	307 5	
3	Pipeline .	71,308	79 5	27,900	58	
4	Power Station buildings, cranes, tail-race, overflow etc	52,195	58	41,804	87 5	
5	Generating plant, switchgear, transformers and machinery ..	1,47,084	163 5	90,834	189	
6	Total ..	4,34,592	483	3,08,030	642	

APPENDIX 5.

Cost of different types of Plant and Equipment.

Item No.	Particulars	Cost in rupees.
Col	1	2
		Rs.
1	Drilling and blasting plant for Headworks, Tunnel, Pipeline and Quarries	3,48,000
2	Ventilation plant for Tunnel	1,52,000
3	Tramway, Rolling Stock and Locos for Headworks, Tunnel and Power Station	6,53,000
4	Lifting and winding gear and winches for Headworks, Tunnel and Power Station	1,10,000
5	Unwatering pumps	63,000
6	Mucking machines, excavators for Tunnel, Power house and Headworks	1,91,000
7	Crushers and screens for Power House and Headworks	79,000
8	Concrete mixers for Tunnel, Headworks and Power Station	34,000
9	Concrete gun grouting machine and cement guns for Tunnel and Power Stations	38,000
10	Forms for Tunnel, Headworks and Power Station	90,000
11	Temporary workshop at Headworks	17,000
12	Rivetting plant for pipeline	10,000
13	General Tools and Plant	3,00,000
14	Temporary water supply for Headworks, Tunnel and Power Station	34,000
15	Lime mortar and mixing plant	6,000

Gross Total .. 21,25,

APPENDIX 6.

Horsepower consumed by various types of plant.

Item No.	Type of Plant.	Horsepower consumed.
Col.	1	2
1	Pipeline winch	120 HP.
2	Winch Camp winch	120 HP.
3	*Each Brot Winch*	*50 HP.*
4	Each electric loco	25 HP.
5	Each mucking machine	10 HP.
6	Each blower set	220 HP max. 38 HP min
7	Each 600 feet compressor	140 HP.
8	Each rock crusher and sand roll equipment ..	60 HP.
9	Motor generator set	80 KW.

The total installed kilowattage of the system is 1,750 Kws. The maximum peak load so far experienced on the whole system is 600 Kws; the resulting diversity factor actually experienced is therefore, 3.

With a peak load capacity of 1,080 Kws. and the same diversity factor, the maximum horsepower which can be installed on the system without additional plant is therefore 3,240 Kws

APPENDIX 7.

Operating costs of power plant.

Item No	Particulars.	Thuji.	Dhelu.
Col	1	2	3
1	Peak load capacity .. .	480 Kw.	600 Kw.
		Rs.	Rs
2	Capital first cost .. .	3,08,030	4,34,592
3	Credits on completion	37,700	80,000
4	Net cost to project . ..	2,70,330	3,54,592
5	Depreciation at 25 per cent (so as to wipe off cost in 4 years of construction) ..	67,582	88,648
6	Interest on first cost at 5 per cent. ..	15,400	21,730
7	Annual operating cost	7,500	20,400
8	Total annual cost of generating power ..	90,482	130,778
9	Cost per Kw. year generated ..	188 5	218
10	Equivalent cost per unit generated on a 50 per cent. load factor basis .	8·2 pies	9 5 pies.

APPENDIX 8.

Particulars of haulageway ropes actually installed.

	Pipe Line.	Winch Camp.
Length	1,600 metres	2,130 metres
Size	36 m/m diameter	28 m/m diameter
Quality of material	Best plough steel. Special acid grade 160/175 kilos per square m/m	
Construction	Flattened strand 6/24 (9×12×3).	
Approximate weight per metre.	5 6 kilos.	3 41 kilos
Actual breaking strain	78·67 tons	48 13 tons
Diameter of wires 9 outer	3·2 m/m.	2 49 m/m
12 inner	1·3 m/m.	1 02 ,,
3 core	2·13 m/m	1·68 ,,
Tests on individual wires	3·2, 1·3, 2·13 m/m	2·49, 1 02, 1·68 m/m.
Breaking strain lbs. (average)	2940, 483, 1302	1775, 294, 809
Elastic limit	60 % to 70 % of ultimate breaking strain of any one wire	
Minimum elongation in 100 diameters	1¼ %	1¼ %
Minimum torsions in 100 diameters.	35	35
Minimum bends of 180° on 5 m/m radius	4-5, 16-18, 9-10	7-8, 22-24, 15-17
Lay of rope	276 m/m.	210 m/m.
Lay of strands	114 ,,	95 ,,
Outside dimensions of Reels.	6′ 1″×6′ 1″×4′ 7″	5′ 11″×5′ 11″×3′ 9″
Gross weight of Reel packing for shipment.	9½ tons	7¾ tons

Material.—The wire from which the above ropes were made was drawn in one continuous length without welds or brazes.

Lubrication.—The ropes were lubricated during manufacture with Craddock's special Rope Composition.

The maximum rope tension when ascending with an acceleration of 1/3 of a foot per second amounts to approximately 11,820 Kg. in the case of the Pipeline, and approximately 8,070 Kg. in the case of the Winch Camp Line, which gives the following factors of safety against breaking :—

Pipeline approximately	6·75
Winch Camp Line approximately	6·05

APPENDIX 9.

Particulars of Electric Locomotive.

The loco is of the combined battery—trolley mining type

Battery.—112 cells, Edison Alkaline, Type A/6

Voltage—1·5 per cell on open circuit Effective volts = 168. Line Voltage on trolley = 220.

Two motors of 25 HP. each.

Tractive effort.—Maximum=4,500 lbs, at 4.8 M. P. H. on 220 volts D. C.

Hauls 25 tons up a 3·5 per cent. grade exclusive of its own weight, or about 90 tons gross on the flat.

The motors which run at 850 r. p. m are located with their axles parallel to the frame and the torque is transmitted to the main axle through single reduction phosphor bronze bearings with ball thrusts.

With the exceptions noted below, these locos have given entire satisfaction.

The trolley poles are too long to swing in the tunnel so that they are only able to run in one direction *on the trolley* in the tunnel. This difficulty has not yet been solved but is under consideration.

We originally specified Davies Centrifugally cast steel wheels. These were unobtainable in the size required and the wheels supplied are too soft and suffer from excessive wear.

The brake blocks are much too hard and are of a peculiar shape; they pressed on the flanges and wore them out. These are being modified and Lignum Vitae substituted.

Weights of Loco:—

Loco with battery	..	..10 tons.
Loco (Trolley only)	..	..10 „

NOTE.—Counterweights and Battery weight—3 tons. Loco is not run without:—

(*a*) Batteries on the Battery-Trolley Type.

(*b*) Counterweights on the Trolley Type.

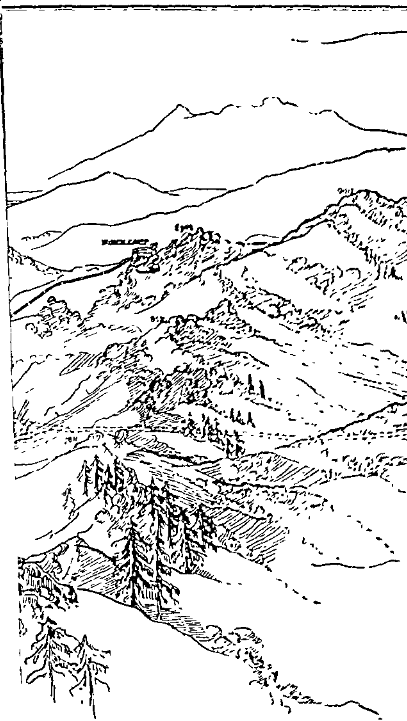
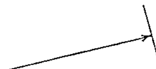


PLATE 3.



R HORIZ = 500

UPPER STATION

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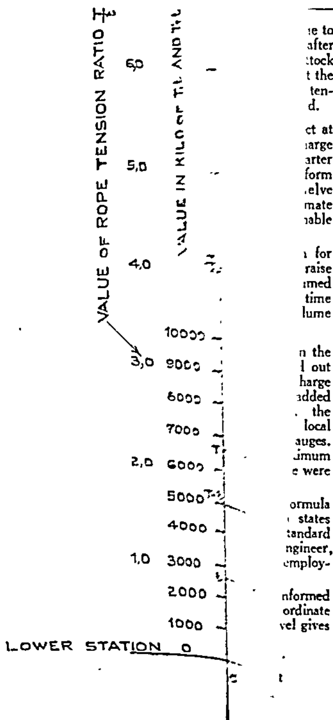
R = 250

36.79 %

5.25 %

R D. 5774
R L. 7309

R D 952
R L 7382.2



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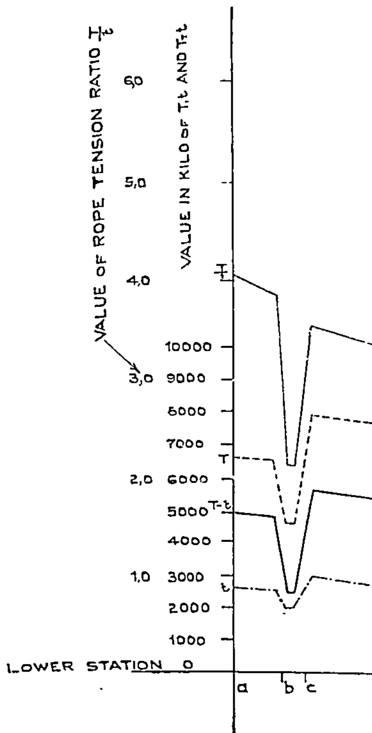
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VALUE OF ROPE TENSION RATIO T/t
VALUE IN KILO OF T, t AND T-t
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4,0
3,0
2,0
1,0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
T/t
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LOWER STATION
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DISCUSSION.

onel **B. C. Battye**—In introducing his paper said that the main f the paper was just to pass on to them the valuable experience ey had gained during the last three years in the designing and on of their construction plant and in doing so he had endeavour- ut before the Congress the fullest possible facts, wherever they le mistakes and wherever they had had trouble it was his experience n learn little from success but much from failure, hence he had put forward every feature of the construction plant used on the Electric Project. There were one or two things he had forgotten h he wanted to draw attention.

ssure of work had prevented his producing the chart or diagram ydraulic works on the north side of the hill, to which he had drawn n, as Drawing No. 7 on page 6

th regard to housing there was little to add except that they l to provide housing accommodation for *every* man on the works as water-supply and sanitary arrangements

nstruction Plant.—There were a few comments to add to what l already said. Since writing the paper they had been able to ate the value of the crushing plant and sand rolls and that by

rning to roads and haulages, at the time of writing the paper, he : in a position to give any definite information with regard to the which had led to the necessity for dismantling and re-erecting the e winch house on the new site Nearly twenty months ago after started to drive the headings of the two pipe tunnels, which run with the pipe line haulage winch house, and which is about hundred feet above, having got in about 50 to 60 feet they noticed that the mediately above the portal had subsided, thereby endangering ndations of the winch house. All tunnel driving was immediately l and a strong anchorage constructed in the heading to hold up and prevent further subsidence This consisted of bunches of ails, the joints between the bunches of rails being made by embed- em in concrete, and was designed for a ground pressure of 500 This stopped all further movement and enabled the existing rein- concrete portal to be installed during the next six months. Driv- then started again but three months later, the winch began to take e power than was normally required and gave indications of being alignment. Levels were taken and it was discovered that the ions had settled: meanwhile the winch house itself and the found- ad cracked in several different directions. It was immediately to dismantle the winch house and foundations and to re-erect ole winch on top of the spur 200 ft. further back. This site s the driver of a view down the haulageway, but ensured a secure

foundation for the future. The new foundation had recently been laid and it was anticipated that the winch would be working again in a few weeks' time. It had been thought at one time that the damage was due to blasting but tests proved that this was not the case and there was now no doubt that the whole site had settled a fraction of an inch as a result of the cracks that had taken place 18 months before The trouble was due partly to the absence of a portal, but more particularly to the cavitation that had take[illegible]
tunnellers w[illegible]
labour had [illegible]
through any [illegible]

One interesting thing that happened was that in shifting the winch house 200 feet back, they had had to add 200 feet to each end of the rope. They knew of no means of satisfactorily jointing such a rope; the Swiss Government did not allow passenger traffic on a spliced rope. The problem was to design a joint which would enable the rope to traverse the rollers or otherwise to purchase an entirely new rope 6,000 feet long. The difficulty was overcome by the introduction of a joint car at a point 200 feet in front of the main car the joint car would stop at the winch leaving the main car to stop at the original transfer station, the site of which had not been shifted This enabled all the additional rope to be obtained from spare lengths available at site and therefore, without any extra cost.

There was a misprint on page 17 of the paper where instead of "98 to 198" it should have been "98 to 108". Their power supply had so far been adequate and they did not anticipate any shortage of power: that was probably due to the diversity factor being higher than they had thought; it looked as if they should be able to get through without any additional power The only trouble they had had was with the Thuji Flume: certain lengths of this traverse very bad ground: leakages had occurred with resulting settlement This had caused several "shut-downs", but the difficulty had now [illegible]
trouble had now been greatly reduced [illegible]
in the methods adopted for laying [illegible]
traffic, but it was too early to be able to give any final conclusions.

Mr. Freak.

Colonel Battye has described an elaborate method of concrete mixing by water cement ratio methods. These methods no doubt give a con[illegible] 4 with [illegible] hether [illegible] extra expense. Have higher allowable stresses been allowed, if so, what has been the saving in [illegible] f the special staff to [illegible]
use the hydrometer [illegible]
the laboratory toget[illegible]

would also ask what happens when the sun comes out or there is a shower of rain? Does concrete mixing have to stop while a fresh hydrometer test is made? He would enquire why mixing by the full bag method has not been used so as to avoid the weighing of the cement?

For running haulageways, electric power was required during construction, but the speaker would enquire whether the two temporary hydro electric power stations put in were the best means of getting that power. The hydro electric plant being only suited for the specific head and quantity of water will have practically no second hand value. The first hydro electric plant at Dhelu owing to an error in the size of the flume, cannot give the power for which it was designed, whilst the cost of the carriage of the second hydro electric plant to Thuji must have been very costly.

The speaker would suggest that oil sets on the Diesel or semi-Diesel principles such as were used at Sukkur should have been installed, with these the amount of power available would have been certain as against the doubtful quantity of power due to lack of water for the Dhelu hydro electric set Oil driven sets of standard pattern could have been readily purchased and quickly installed and so allowed construction to have been put in hand quicker Most important of all, oil driven sets would have had a useful second hand value on completion of construction For the subsidiary machines such as air compressors, concrete mixers, the author had adopted electric drive in every case, which again will mean that the machines will have little or no second hand value in India. The usual practice is to have a separate oil engine for each machine and then the machines would have been standard and would have had a useful second hand value.

With electric driven machines, commencement of work had to be delayed until electric power was available

The author mentions an eletric driven excavator; the speaker would enquire whether there has been sufficient work to justify an excavator at all. This again being electrically driven will have practically no second hand value In the figures for the cost of the excavation with this machine, no detail of the lead has been given

Lastly with regard to the housing, in the beginning brick panels were used and later plastered expanded metal The speaker would ask which method has been the cheaper and why bricks were ever adopted with the bad brick earth available at the site?

Mr. Mool Chand Sharma.

He described the discharges of the rivers of the Punjab and compared them with the discharges of the Uhl (Beas). With reference to the working of the Dragline he wished to ask Colonel Battye what was the interest and depreciation referred to in the last sentence on page 7 of his paper: The lowest cost in any one month (exclusive of interest and depreciation on the machine) was Rs. 34-2-3 per thousand cubic feet. He

said that in Delhi he had been able to do similar work at Rs. 20 for the hardest sandstone

L. Brij Mohan Lal.

He referred to Appendices 4 and 7 and enquired why the peak load capacity for Dhalu was 600 k.w. only when the k.w.s. installed were 900.

As regards the points raised by Mr. Mool Chand, about the excavation cost, he said that the usual rates for excavation of rock by blasting in the Kangra Valley were Rs 40 per thousand cubic feet. In the Uhl River Project the cost was Rs 34-8-0 per thousand cubic feet by the electric excavator excluding depreciation and interest charges. He said that the cost might come to Rs 60 per thousand if the latter were included. Thus the work of the excavator was too costly.

Mr. Nicholson.

He referred to the methods adopted for the transportation of plant and machinery to the Headworks on the other side of the hill, and enquired if it would not have been preferable to have driven the tunnel heading first and take the material for construction of the works in the Brot Valley through it.

This would have saved the extra haulages over the hill.

Colonel B. C. Battye (reply)

Mr Freak's points were in connection with concrete. He did not hope to save money by getting more highly stressed concrete and using higher stresses in the design, the chief effect of this method was:—

(1) That they could get more uniformity in their concrete, the result of which was that they could be *certain* of their concrete When lining pressure tunnels, where there can be no question of ever being able to carry out repairs, reliability of the concrete is of vital importance—far more so than economy.

(2) This method often resulted in a cheaper concrete, *e.g.*, in the building of the tunnel portal, they had found that, in actual practice by the adoption of these methods, it had been found that the actual mix, instead of being 1 : 2 : 4, it worked out to 1 : 2¼ · 4½, so that an appreciable saving had been effected in the cost of the concrete by the adoption of these methods.

There was of course some extra cost involved in the laboratory staff, but that is the only extra cost: they do not find that any extra establishment had to be maintained for proportioning and mixing. Any intelligent overseer could pick up the idea without extra training and was able to control it without extra staff. The equipment costs a trifling amount compared to the value of the work that is handled.

As regard the question of having a hydrometer on the works, in a very short time th[illegible]
14 per cent mois[illegible]
about 7 to 10 per [illegible]
per cent it was go[illegible]
or twice a week (or get these checked for him) in order to keep the water cement ratio constant The methods adopted were not highly abtruse or complicated and it was found in practice that an ordinary S. D O could be trusted to use his judgment

With regard to electric power, Colonel Battye pointed out that the Appendix was an attempt to arrive at the actual cost of these plants after writing off the whole capital cost during the period of construction less the small credits noted, a considerable portion of which in the case of Thuji was a genuine credit because the whole of the electrical portion of this plant would afterwards be installed as auxiliaries in the main power station.

Their prices per unit were 9½ pies Now no fuel plant could possibly be installed on the works and hope to generate at these figures, from either oil or coal

With regard to the electric drive, on all such works, concentrated in the area [illegible] driven construction plant was, as [illegible] other types and could of course b[illegible]

There was enough work for the excavator · it had been kept running for 16 hours a day for the last three years and expected to be used for another 2. There was plenty of work for it and it had undoubtedly speeded up work and enabled them to carry out all surface excavation more expeditiously. The excavator handled heavy stuff, i e., boulders from 4 to 6 feet in diameter, stacking them to one side upto 15 feet high. They had found in practice that the cost of working and maintaining the excavator was about equal to the cost of the actual bills paid to the contractor where small numbers of men were employed The hills usually sloped 1 in 1 and they were perpetually faced with the problem of finding sites for housing men and foremen The general feeling was that, putting aside the problem of housing and looking after labour on the one side, and depreciation and interest on the other, there was very little to chose either way. the general feeling was that the excavator had justified its use, and that labour saving devices in a country of this nature were justified every time, provided that hydro power could be obtained at a reasonable cost.

[illegible] cost of this [illegible] was available, [illegible] l supply, the [illegible] odifying the Armco flume so as to ensure its being able to give the full supply was trifling compared to the whole capital cost, so that the figure per [illegible] installed was correct within one or two per cent.

Mr. Nicholson's proposal to drive the tunnel through first and then use it to provide transportation facilities in to the Brot valley, had never be n seriously considered. The time for driving the main tunnel was the governing factor on the whole project and even if they had been able to start driving a year earlier, which might have been possible if they had installed steam driven compressors in the valley below and piped the air to site, they would not have been anywhere near through the hill even by now and would not therefore, have been in a position to start the construction of the hydraulic works in the valley for at least another year. He thought that it was quite possibly true that if they had installed steam driven compressors in the valley below, they might have saved time [illegible]

With regard to Mr. [illegible]
ciati[illegible]
sub-[illegible]
at the moment to give exact figures for interest and depreciation on the cost of the excavator

PAPER No. 134.

HYDRAULIC OBSERVATIONS ON THE SHYOK FLOOD OF 1929.

By J. P. Gunn.

Early in 1929 it fell to my lot to go to Ladakh and investigate the glacier dam that had formed on the Shyok river ; one of the objects of the expedition was to ascertain, if possible, what would be the effect near Attock of water released by the bursting of the dam.

On the way up to the dam I investigated the traces left by the flood of 1926 and tried to work out something whereby an approximate prediction might be possible.

I inspected the dam from below and then made a detour and got up to the lake. After the survey of the lake had been done the dam burst, and on the return journey I made such observations as were possible of the flood marks at various places. These observations differed widely from what I expected and it is for this reason that I put forward this paper.

Some of the assumptions made in it are bold in the extreme, while the prediction curves are nothing more or less than arguing from the particular to the general, but I can see no other method of dealing with the question. All I can hope is that this struggle to produce results, with insufficient knowledge of the nature of turbulent flow of water, and unreliable data, may inspire some one to carry out investigations to clear up some of the problems set out for consideration.

Shyok river.

To enable the nature of the Shyok river bed to be appreciated I have given longitudinal sections at Sasir Brangsa and from Sati to Diskit and a rough plane table sketch of the course of the river in the latter reach in plates II to IV. The points at which the 1926 flood levels were observed along with their values are shown on the plane table sketch, the underlined values show the 1929 flood levels.

The cross sections at the gauge site, plate V, were taken along a line which I anticipated would be at right angles to the direction of the current during floods. I selected a site on the left bank above Khalsar for the gauge where a cliff rose straight out of the water. From our information it seemed that the water surface here was more or less level in the 1926 flood, but this year's flood which gave 28 feet cross slope at this point shows that either the nature of the flow was different or that our original information was incorrect The latter is probably the case as no flood marks could be seen on the rock. The local inhabitant had no interest in that particular spot and probably drew on his imagination.

As can be seen from the cross sections, plate V, the river during the flood scoured its bed about nine and a half feet at the site of the gauge and concentrated the flow into one channel.

In the reach from Sati to Diskit the general slope of the water surface over a distance of about twelve miles is 3·75 feet per thousand feet or 18·75 feet per canal mile of 5,000 feet. In the upper reach above Sasir Brangsa the slope over about six miles is 8·20 feet per thousand feet or 41 feet per canal mile, while in one reach it drops fifty feet in half a mile. These mean slopes of 3·75 feet and 8·20 feet per thousand feet have been adopted in the calculations of discharges.

Cross sections of the Shyok between Sati and Diskit are reproduced on plates VI and VII as an indication of the general nature of the bed and explain why the seemingly open bed at the Shyok-Nubra confluence has such a slight effect on the flow.

The flow in floods is extremely turbulent and influenced largely by local conditions. I have therefore not attempted to draw a longitudinal section to show the high flood levels but have indicated the position of observed points with their values. It will be seen from the sketch on plate IV that the floods of 1926 and 1929 varied greatly in height over a comparatively short distance.

Flood levels.

Taking the right bank of the river, where the marks of the 1929 flood were in general better defined, half a mile above the gauge the 1929 flood was 18 feet higher than that of 1926, at the gauge it was only 8·47 feet higher, while six miles further down in the region of Thirit differences of 46·2 feet and 47·19 feet were observed ; as the levels were followed up the Nubra towards Teggur the difference gradually fell off to 16·48 feet.

It will be seen from these figures that it is impossible to compare the magnitude of any two floods by a comparison of their maximum levels observed at any one place. Without some such observations it is almost impossible to conceive the irregularity of flow that occurs during floods, and I am of the opinion that no gauge set up in the Shyok can give a quantitative prediction of the effect at Attock.

Flood travel.

The rate of travel of the floods of 1926 and 1929 is given in the table below. The distances have been scaled off the latest available ¼" maps while the times have been obtained by local enquiry and can only be taken as approximate. The same information is plotted on plate VIII and shows a fairly satisfactory agreement between the data. This plate also shows the mean velocities and velocities as calculated in table 3 for certain points. The actual times from the warning gauge at Khalsar to Attock were approximately fifty-six hours for the 1926 flood and fifty-nine hours for the 1929 flood.

Table 1.

Serial No.	Particulars.	No. of miles (distance travelled).	No. of hours.	Velocity in miles per hour.	Velocity in feet per second.	Mean velocity in feet per second.
	Flood 1929.					
1	Sasir Brangsa to Khalsar	130	22	5·91	8·67	12 31
2	Khalsar to Skardu .	165	16	10 31	15·12	
3	Skardu to Bunji ..	96	14	6 857	10 06	
4	Bunji to Attock ..	289	29	9 965	14·62	
		680	81			
5	Attock to Kalabagh ..	99	8½	11 65	17·08	
	Flood 1926.					
1	Diskit to Skardu	153	16	9 56	14 03	14·47
2	Skardu to Bunji	96	8	12 0	17·60	
3	Bunji to Chilas	47	5½	8 55	12·53	
4	Chilas to Attock	242	25	9 68	14 20	
		538	54½			

Gapshan Lake

It is not practicable to reproduce the map of the lake to original scale, but plate IX shows a reduced map on a scale of 1" to a mile as surveyed. The contours can not be reproduced but the lines on which soundings were taken are shown together with the level of the bottom, plate X shows the area at each contour plotted as a curve and the table shows the actual areas together with the volumes between successive contours and the total volume up to any contour, this last quantity is also shown on the diagram as a curve

From observations taken during our stay at the lake we found the total rise, which was nearly uniform, was 5·9 feet in 211 hours giving a daily inflow of 6,581 foot-acres per day. The total volume in the lake was 1,095,500 foot-acres.

To get an approximation to the rate of inflow in a year I made certain assumptions. I had taken that the burst in 1926 occurred late and that there would be no more melting that year, or rather that the dam reformed before the melting in 1927 began, and that there was no water left after the 1926 burst. Also I neglected evaporation and absorption and assumed that the water in the lake was the result of three years' melting. This gave an average annual inflow of 365,000 foot-acres.

To check these assumptions I referred to Mr. Ludlow who stated that, at the time of his visit in 1928, a slight fall of snow occurred on the first night he reached the lake and that the next two days were abnormally hot; he considered that the inflow was probably above the normal; his estimate of the rate of rise was about 1½ foot per day for the two days he was there. It was almost exactly a year later that we visited the lake so that at the time of Mr. Ludlow's previous visit the volume in the lake would probably be 730,000 foot-acres. From the curves this gives the level of the water as 15,850 and the area about 7,300 acres. This gives a rise of 0·9 feet per day for normal inflow. Considering the difficulty of estimating a rise in water level, and the light snowfall followed by abnormal heat, I consider that we may accept the figures and presume that the assumptions are correct.

To get some idea of the variation in the rate of inflow I have based an estimate on the discharge of the river at Khalsar. The river above Khalsar is almost enirely glacier fed but in the early part of the year much water will come from the snow melting. As the flood scoured the bed down low at the gauge site the discharges for a whole year are not available I have however plotted on plate XI a curve of the monthly mean maximum temperatures at Leh and Dras, both a mean of years and this year's mean, and also on the same time scale a curve of discharges at Khalsar. By assuming that the general shape of the discharge curve will conform to the temperature curve, I have taken the mean daily discharge for each month at Khalsar and assumed that the inflow into the lake occurred in the same proportion. The results are given in the table below, from which it is possible to forecast roughly what the level of the water in the lake will be in any month when one observation of the water level is available in any year.

Table. 2.

Month.	Assumed discharge at Khalsar, cusecs.	Assumed monthly inflow at Lake, foot-acres.
June	1,000	5,183
July	22,000	114,610
August .. .	35,000	182,500
September	12,000	62,514

Attock gauge. As the main object of the expedition was to ascertain the probable effect at Attock of a flood from the Shyok, I devoted some time to trying to get a calibration curve for the Khairabad gauge situated a mile and a half above Attock Bridge. The only data available from which this could be done were the daily discharges observed at Kalabagh a hundred miles below Attock. These observations are made with current meters, observing the mean velocity in low supplies and surface velocities in high

while surface floats are used when the discharge is very big and velocities too high to enable a boat at anchor to remain steady.

Owing to the river bed at Attock silting and scouring it was not possible to get any results from points that were not selected with care, but after allowing for time-lag and selecting points when the river discharge was steady and conditions generally indicating no abnormal silt I derived the formula—

$$\log Q = 0.805 \log G + 4.3014$$

for Khairabad. The range of observations for which this appeared to hold is between gauges of 5 feet and 30 feet with discharges of 70,000 cusecs and 300,000 cusecs respectively. From this I plotted a time-discharge curve from the observations available, plate XII, for Khairabad.

I also endeavoured to find a similar relation for the Attock Bridge gauge but the channel section is not so uniform there and I could get no satisfactory curve.

Like all empirical formulae this discharge equation needs to be applied with care and can only be expected to hold for a certain state of the river.

The Indus had been running with a discharge of 200,000 to 300,000 cusecs from the middle of July and had reached over 400,000 cusecs on the 2nd August at Kalabagh falling to 200,000 on the 11th and had only increased slightly to 237,000 on the 17th, from which one would expect a certain amount of silt to have been deposited and not removed up to the 17th by the gradual rise of the river. That this discharge is below the formula discharge was only to be expected. The deposit however would readily be moved by the rapidly rising flood and I have adopted the formula discharges for the rising river and peak discharges. On the falling river silt must again have deposited, and so long as the formula gave a fairly uniform rate of fall in discharge I have adopted these discharges; but from 8 A. M. on the 20th I have adopted lower discharges following approximately the same rate of fall, as the comparatively sudden change in slope of the curve indicated that silt was depositing.

I have taken as the Indus component of this flood 237,000 cusecs as that discharge was measured at Kalabagh on the 17th and 22nd and brought the time-discharge curve for Attock to this value on the 21st to allow for time-lag. There was little rain during the 19th and 20th anywhere in the Indus Valley but after the 21st a gradual rise set in and perhaps the discharge on the closing day gives the Indus credit of a slightly larger quantity of water than it should.

Treated by this method, however, the total run-off in three days at Attock due to the Shyok dam bursting comes to 884,300 foot-acres as compared with 1,095,500 foot-acres in the lake. In the case of the similar flood in 1926 approximately 10 per cent. of the total run-off, as ascertained from the records of the Discharge Division, occurred after

the third day, but in the case of this flood the river started to rise due to rain and no proper account can be kept of the Indus component after the third day. The agreement between the calculated run-off at Attock and the quantity in the lake is reasonably close and would show that the formula gives reasonably close results for flood peaks, and the extension of the formula beyond the range of observations seems justified.

The only way which I see of making any estimate of the effect at Attock of a burst in the Shyok dam depends on the use of this discharge diagram. From the diagram it appears that aproximately a quarter of the total volume in the lake passed Attock with a fairly uniform discharge in twelve hours. The dotted lines show the twelve hours interval, and from this it would appear, possible to estimate the Attock discharge from the volume of the lake within reasonable limits.

The following method was adopted in preparing a diagram for predicting the heights to which a flood from the Shyok dam might raise Attock Gauge. One quarter of the total volume of the lake is presumed [illegible] that is what the time [illegible] quarter of the volume [illegible] ecs [illegible]

It is also assumed that, no matter what the amount of silt in the bed of the river before a flood is, in high flood the silt is scoured out and the formula gives the discharge passing. The standard discharge for various gauges at Attock was then calculated, to these were added successively the expected flood discharges from the lake and the corresponding gauges calculated. To allow for the effect of local heading up a margin of five feet was added to the calculated gauges. Then taking the gauges before the flood as abscissae and the maximum flood gauge as ordinates curves for each depth of water in the lake were drawn. See plate XIII.

To allow for the probable departure from the standard formula discharge three more scales are shown. These correspond to states of the river when two, four and six feet gauge above the standard are required to give the formula discharge. The Executive Engineer, Discharge Division, can tell at any time which scale should be employed.

The method of using the curve is simple. On being informed which scale of abscissae is to be used, the intersection of the ordinate through the gauge reading of the day and the curve of lake level gives the height to which the Attock Gauge may be expected to rise.

I do not consider this method of flood prediction very satisfactory owing to the vast number of uncertain factors involved but at least it will give some guide. Also as the level of lake this year was within a small distance of the maximum traceable lake level it is unlikely that a greater effect will ever occur at Attock.

Hydraulic Formulæ. The following paragraphs deal with certain aspects of turbulent flow and give some guides for experimental investigations that may be valuable where not actual flood levels, but volumes passed, are under consideration.

With a view to ascertaining, if possible, how far the formulae for smooth flow could be adapted to flood conditions by a modification of the constants, I examined such data as were available at various sites and made use of the fact that the volume in the lake was known.

The data for the upper reaches of the Shyok are unsatisfactory from the point of view of any great accuracy but even then they give valuable indications.

At Sasir Brangsa it was possible to obtain fairly satisfactory cross sections as the ice had left berms at various points, but the man, who is stationed there to conduct caravan across the ford, could not give any reasonable idea of the times at which these levels occurred. On the 18th he stated originally that the dam had broken on the 14th instead of the 15th, and I am very doubtful altogether of the times at which he states the levels occurred.

At Khalsar the times were probably more or less accurate as far as could be judged but only levels on the left bank at the gauge could be got with any accuracy as no marks were visible on the right bank.

At Skardu levels were read off the gauge and times taken with a watch but as the gauge was washed away the rate of fall below 25 feet is conjectural.

Unsatisfactory as these data are, the results of calculations indicate that the conventional co-efficients in the usual formulae are far from correct for turbulent flow such as occurs in floods.

The method of examining the data was based on Manning's formula $V = \frac{1.486}{n} \times S^{\frac{1}{2}} R^{\frac{2}{3}}$ in which n has the same value as in Kutter's ormula. I assumed that the portion $\frac{1.486}{n} \times S^{\frac{1}{2}}$ remained constant for each site throughout the flood Then from the observed cross sections shown in plates V, XIV, XV, the area and hydraulic mean radius were calculated for each stage. The Attock and Kalabagh data were given by this discharge division.

The discharge for each stage is given by—

$$Q = A \times R^{\frac{2}{3}} \times \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}} = K A R^{\frac{2}{3}} \text{ say.}$$

Plotting the quantity $A\ R^{\frac{2}{3}}$ as ordinate on a time basis the area of the curve when multiplied by the factor K, assumed constant for each site, gives a cusec-time quantity which is readily convertible to foot-acres.

By equating the volume of the lake in foot-acres to this quantity the value of K is easily determined. In the diagram shown on plate XVI one square is equivalent to 8 × 2000,000 K cusec-hours or

$$\frac{8 \times 200\,000 \times 2}{24} \times \text{K foot-acres}$$

In the case of Skardu, Attock and Kalabagh a correction was applied for the amount of water already in the river when the flood came down, but in the case of Sasir Brangsa and Khalsar the time of passing the flood was short and the initial discharge small and no correction was made.

At Skardu the discharge of the Indus was estimated by assuming n='030 and working out the initial discharge from the cross section, hydraulic mean radius and slope at Attock and Kalabagh the correction taken was the measured discharge of 237,000 cusecs.

A table is given below showing the quantities for the various sites, the calculations for each site are shown in detail in Appendix F, [illegible] also plate XVI:—

Table 3.

Serial No	Sites.	Slope per thousand	Area.	H M R	K	Discharge.	n.	[illegible]
1	2	3	4	5	6	7	[illegible]	[illegible]
1	Sasir Brangsa	8 2	133,400	54 67	0·82	1,674,120	[illegible]	[illegible]
2	Khalsar	3 75	104,896	48 00	1 05	1,454,000	[illegible]	[illegible]
3	Skardu	2·00	57,300	25 80	2 009	1,005,000	[illegible]	[illegible]
4	Attock	0 .9	51,875	58·50	0 815	637,020	[illegible]	[illegible]
5	Kala bagh	0 50	32,658	30·10	1·57	496 400	[illegible]	[illegible]

These variations in "n" are remarkable from the [illegible] obtained, a certain variation was to be expected but these [illegible] would indicate that turbulence has an effect vastly in excess of [illegible] expected.

During this flood certain observations were taken [illegible] calculations made on the usual departmental lines to [illegible] maximum discharge. Owing to the sudden nature of the [illegible] observers were only able to obtain four surface velocities [illegible] ing logs. Then calculating from a previously observed [illegible] and applying a factor of 0 9 to reduce the observed velo[illegible] velocities a discharge of 841,000 cusecs was calculated [illegible] from an assumed value of Kutters "n" of '025 and the [illegible] observed cross section a discharge of 755,000 cusecs was [illegible] against a maximum of 511,300 given by the formula.

If either of these values be accepted as the maximum then the run off at Attock would be vastly in excess of the volume of water contained in the lake. From this it can be seen that the co-efficients in general use for flood discharges are open to grave doubts. However, in the absence of any other formulæ it is necessary to see what constants are desirable to bring the calculated results more in accordance with the actual discharges.

Some light may be thrown on the question by the examination of the discharges at Attock. By this method of calculation a value of n= ·0315 is obtained, while a calculation of the discharge based on a cross section and slope of the river with a value of n=·043 gives a discharge of 5,10,917 which is very close to the discharge given by the logarithmic formula. The difference between these two values of "n" is not hard to explain, the increase is due to turbulence and as turbulence increases so the value of "n" rises to a maximum of ·043 while the value of 0315 is an intermediate value between the maximum and the ordinary value of n=·020 This implies as might be expected that the co-efficient K is not a true constant for the whole range of the flood at any site but varies with the degree of turbulence. This indicates that the values tabulated for the various sites are not absolutely the maximum values, but some intermediate values. The value of ·0872 for Khalsar is vastly in excess of the value of ·030 obtained from a discharge at low water.

Nearly all the discharges of rivers and torrents in heavy flood depend on surface velocity observations and here again a check on the conventional co-efficient of 0·9 is afforded by the calculated discharge at Attock.

Taking the discharge given by the logarithmic formula as correct a mean velocity of 9·86 feet/second is deduced from the area of the cross section, against a mean velocity of logs observed as 18 02 feet/second and from this it appears that the co-efficient used in the discharge 0 9 should be 0·55. It must be carefully noted however that the velocity of logs is not a true surface velocity, far from it; however *as long as the only practicable way of observing flood velocities is by* timing objects floating past it would seem desirable to reduce the co-efficient.

Nearly all our observations of daily discharges in high rivers depend on surface velocities and it would appear imperative to carry out some investigations to ascertain more exactly the relation between surface velocities and mean velocities in turbulent motion. I do not consider the results given above to be sufficiently accurate to justify the adoption of these co-efficients without further enquiry, but I consider that no storage project should be entered into till some further information is available on these points.

APPENDIX A.

SKARDU GAUGE.

While at Leh a telegram was received from the Chief Engineer stating that the gauge at Skardu was reported to be damaged and instructing us to see what could be done to put this right. I consulted the Tehsildar, Leh, who had been transferred from Skardu only a few months previously, as well as the Wazir Wazirat, who has his winter headquarters at Skardu. Both these officers knew the gauge well and on their information I decided to send B. Abdul Rahim to carry out the necessary work.

[illegible]

to carry on this graduation downwards as the water fell.

A cross section of the river at Skardu gauge site was also taken and is shown in plate XV.

After completing this work B. Abdul Rahim reached Srinagar on September 29th.

APPENDIX B.

Flood Warnings.

As already mentioned the system for conveying warning of a flood in the Shyok due to a burst of the Chong Kumdun dam depended on a gauge reader at Khalsar and three pairs of dak runners, one of each pair had always to be present at his post. To avoid any delay in conveying the warnings horses were to be provided for the dak runners in the event of a burst.

To get the system into working order the gauge reader at Khalsar sent off postcards with gauge readings to the Executive Engineer, Discharge Division, by one of the runners, while the other had to remain at his post It was arranged that in the event of a flood the gauge reader should send a special letter to the Wazir Wazirat, Leh, stating at what time the flood began to rise, the height reached on the gauge and the time during which the water remained at this highest reading.

The necessary authority was issued for the Wazir Wazirat to send "clear the line" telegrams to the Punjab Government regarding any flood.

The system worked satisfactorily when the flood came at 8 A. M. on the 16th; information reached Leh in twelve hours, the messengers having started from a height of 10,000 feet, crossed a pass 17,600 feet high and dropped down to 11,500 feet at Leh in a distance of 37 miles, and the warning wire from Leh was delivered in Simla at 6-15 A. M. on the 17th.

While the warning system worked satisfactorily this year the danger of relying solely on these measures to communicate with Leh lies in the fact that the Khardung pass is frequently closed for two or three days at a time due to storms even during the height of summer. It is even more undesirable to employ a system of bonfires or other visual signals over the pass as quite frequently clouds gather on it for days on end though there may be no heavy precipitation.

I therefore strongly recommend that a duplicate warning be arranged for from Skardu. The flood reached Skardu very few hours after this year's warning reached Leh and the two wires should arrive at almost the same time.

I recommend that the following works should be undertaken as soon as possible next year so as to facilitate the prediction of the amount of water in the lake and also to give some idea of the size of any future flood.

At the lake itself I recommend a series of cairns suitably marked be erected at each fifty and hundred foot contour level working from the bench mark fixed by the party this year. These should so far as possible be erected along some even slopes in straight lines and a section of the ground supplied to the Punjab Government so that it may be possible for any one in future to report that the water level was so many paces from a certain cairn, on receipt of this information the water level could be derived from the section. This would enable the volume of water to be estimated from the curve in plate X.

At Khalsar the rock is rough and I do not anticipate that after a few years the marks made this year will remain visible. I therefore recommend that the gauge at Khalsar be properly dressed in a smooth strip, graduated by feet and quarter feet from as far as possible below this year's zero up to a 10 foot reading, after this only feet need be graduated up to a level about five feet above this year's flood level.

These works could be readily done by the Kashmir State Public Works Department who have an overseer at Leh.

Then in any year in which it is reported that the dam exists a gauge reader and dak runners should be engaged to work between Khalsar and Leh, and a man despatched to the lake as soon as the Sasir pass is open to report the water level in the lake and the state of the glacier.

I do not consider it necessary to wait for any information about the duration of the flood peak in future as even the maximum gauge reading cannot be relied on for a prediction and the height of the flood peak at Attock is determined from the volume in the lake. The orders for the gauge reader would be to report the time at which the gauge began to rise and the height to which it rose.

At the same time I recommend that the Skardu gauge be read and reported regularly in future.

The necessary authority should be arranged for the Wazir Wazirat and Tehsildar Skardu to send "clear the line" messages to the Punjab Government about any flood. The duplicate warning is necessary as the Khardung pass may be blocked, or the telegraph line to Skardu may be out of order as was the case this year.

APPENDIX C.

1929 Flood Rises.

Sasir Brangsa. The dam broke in the early hours of the 15th August, and the flood reached Sasir Brangsa, 10 miles below the dam, at about 6 A. M., it rose 85 feet in four hours to about 10 A M., and remained at this level till about 11 A. M. After this the water gradually subsided and fell 52 feet in six hours to a level 33 feet above the morning gauge by 5 P. M. After this the fall was very slow and in 24 hours the fall was nine feet, that is according to the statement of the man in charge of the ford, and on the 16th at 5 P. M. the water was still 24 feet above its initial level, while on the 17th morning the level was little above normal

Khalsar. The flood reached Khalsar about 8 A. M. on the 16th August, and rose 45 feet from a gauge of 8 feet to 53 feet in about half hour, it remained at this level up to 10 A. M. and then rose suddenly 18 feet to a gauge of 71 feet at which level it remained till 3 P. M. giving a total rise of 63 feet. After this it dropped 50 feet in an hour to a gauge of 21 feet and continued to fall and by the 17th morning the water was 9½ feet below its original level on the 16th

I am of the opinion that the sudden rise at 10 A. M. and fall at 3 P. M. of the gauge was due to movement of a large shingle bar.

Skardu The flood reached Skardu at 8-30 P. M. on the 16th, the gauge being 17 feet at 6 P.M By 9 P. M. the gauge had risen 8 feet in half an hour to a gauge of 25 feet, it reached its peak of 42 feet at midnight having risen 17 feet in 3 hours. The water remained at this level up to 3 A. M. on 17th, after which it dropped 7 feet in 4 hours and stood at a gauge of 35 feet at 7 A. M. The gauge was carried away but the fall continued, and it is estimated that the gauge was about 19 feet at 7 P. M. on the 17th.

Bunji According to information received from the Resident in Kashmir the flood reached Bunji at 5 A. M on 17th August and rose (presumably from 7 feet) to 31 feet at 8-10 A. M. and reached its peak of 44 feet at 1-45 P. M. At 7-50 P. M. it subsided from 44 feet to 34 feet and early in the morning of 18th August it fell to 19 feet finally falling to 7 feet at mid-day.

Attock. On the evening [illegible]

[illegible]

risen a further 6 [illegible]

a further 4 5 feet [illegible]

reached at 6 P. M. [illegible]

The gauge remained steady at the peak for about 2½ hours and then began to fall, reaching a gauge of 50 feet at 6 A. M. on 19th August. It fell 4½ feet by 11-30 A. M. and by 5-30 P. M. had fallen to 40 feet. The fall then became more gradual and the gauge of 28 feet was reached at 8 A. M. on 21st August.

APPENDIX D.

Flood Levels at Attock.

The observations of flood levels taken this year showing the Shyok flood on the 18th August as well as the flood on the 28th August are shown in plates XVIII to XXI, while an index plan showing the position of the cross sections is shown on plate XVII.

The levels of the flood of 1841 are also shown on the plates for purposes of comparison. Taking into consideration that the volume impounded by the dam this year, was very nearly the maximum ever held up it is obvious that the menace from the Shyok is not so great as had been anticipated.

A certain amount of heading up occurred at Attock due to the Shyok flood, but this was not of long enough duration to affect the Kabul river very far up, while the rain flood had a very much greater effect.

It can be clearly seen that no rain flood could produce levels equal to the flood of 1841.

The flood in 1841 was due to a block at the Hatu Pir spur of Nanga Parbit. A portion of the hillside fell into the river bed and completely blocked the Indus for about six months. When this dam broke a tremendous volume of water was let loose. It is only from some similar catestrophe that the levels of 1841 could again be reached.

APPENDIX E.

CALCULATION OF HYDRAULIC CONSTANTS.

Sasir Brangsa.

The table below shows the various quantities got from the cross section and the product $AR^{\frac{2}{3}}$ *for Sasir Brangsa.*

	Area.	W. P	H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.
Stage 1 ..	133,400	2,440	54 67	14·4	1,920,960	8 2 or S=·0082
,, 2 ..	26,220	1,270	20 65	7·52	197,174	
,, 3 .	16,460	980	16 79	6 55	107,813	

The quantity $AR^{\frac{2}{3}}$ is plotted on a time basis. Taking 8 hours per inch and 200,000 per inch as the unit for $AR^{\frac{2}{3}}$.

The area of this figure comes to be 10 sq. ins. Then area in sq. ins. $\times 2 \times K \times \frac{8}{24} \times 2$ = lakhs of foot-acres in lake.

$$\frac{10 \times 4}{3} K = \text{Volume of lake in lakhs of foot-acres,}$$

$$= 10 \; 95$$

$$\therefore K = 0{\cdot}82$$

$$\text{and } 0{\cdot}82 = \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}}$$

$$= \frac{1{\cdot}486}{n} \times {\cdot}0082^{\frac{1}{2}}$$

$$n = 0{\cdot}1651$$

$$\left\{ \begin{array}{l} \text{mean velocity} = R^{\frac{2}{3}} \times K = 14{\cdot}4 \times 82 = 11{\cdot}8 \text{ ft./sec.} \\ \text{peak discharge} = A \times V = 133{,}400 \times 11{\cdot}8 \\ \qquad = 1{,}574{,}100 \text{ cusecs.} \end{array} \right.$$

Khalsar.

Calculations of Shyok Flood Discharge at Khalsar.

	Area.	W.P.	H.M R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand
Stage 1 .	86,022	2,167	39 69	11·63	100,436	3 75 or S=·0038
„ 2	104,896	2,185	48 00	13 21	1,385,676	
„ 3 .	32,575	1,724	18 89	7 09	230,957	
„ 4 ..	..	..	..	..	11,604	

Area of $(A \times R^{\frac{2}{3}}) \times 2\,K \times \frac{8}{24} \times 2$ = foot acres in lake

Area by diagram = 7·80 sq. ins.

$\therefore 7{\cdot}8 \times \frac{4}{3} K = 10{\cdot}95$

or $K = 1{\cdot}05$

and as $K = \frac{1{\cdot}486}{n} \times S^{\frac{2}{3}}$

$\therefore \quad 1{\cdot}05 = \frac{1{\cdot}486}{n} \times {\cdot}0038^{\frac{1}{2}}$

$\therefore \quad n = 0{\cdot}0872$

and mean velocity $= R^{\frac{2}{3}} \times K = 13{\cdot}21 \times 1{\cdot}05 = 13{\cdot}87$ ft./sec.

$\therefore$ Discharge $= A \times V = 104{,}896 \times 13{\cdot}87$

$= 1{,}454{,}900$ cusecs.

In the original drawing from which these calculations were made the scales used for Skardu, Attock and Kalabagh were 1″ = 8 hours and 100,000 = 1″ for the $AR^{\frac{2}{3}}$ scale, but they were replotted to the same scales as Khalsar and Sasir Brangsa on plate XVI for purposes of comparison.

Skardu.

In the cases of Skardu due allowance must be made for the water already in the river.

To estimate this calculations for stage 4, *i. e.*, a gauge of 17 ft., were worked out assuming a value of n=0 030,

$\cdot\ Q = A\,V = A \times \frac{1{\cdot}49}{n} \times S^{\frac{1}{2}} R^{\frac{2}{3}}$

$= 14{,}670 \times 11{\cdot}30$

$= 165{,}771$ cusecs.

As the period of passing of the flood was 48 hours the volume passed by the normal river supply is 165,800×4 foot acres = 6·63 lakhs of foot acres.

The quantities in the table below were then plotted on a time base.

	Area.	W.P.	H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.	Remarks
Stage 1 ..	26,110	1,605	16·27	6·42	167,626	2·0	
,, 2 ..	57,300	2,220	25·81	8·73	500,229	or S=·0020	
,, 3 ..	43,710	2,370	18·44	6·98	305,096		
,, 4 .. with gauge 17 ft.	14,670	1,288	11·4	5·07	74,377	..	Flowing at normal conditions

Then K × area or curve × $\frac{2}{3}$ = Volume in lake, + volume in river for 2 days.

or $13{\cdot}2 \times \frac{2}{3} \times K = 10{\cdot}95 + 6{\cdot}63$

i. e. $K = 2{\cdot}009$

since $K = \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}}$

$2{\cdot}009 = \frac{1{\cdot}486}{n} \times {\cdot}0020^{\frac{1}{2}}$

$n = 0{\cdot}0332$

and mean velocity $= R^{\frac{2}{3}} \times K = 17{\cdot}54$ ft./sec.

and discharge $= AV = 57{,}300 \times 17{\cdot}54$

$= 1{,}005{,}040$ cusecs.

Attock.

In the same way, for Attock, assuming that the water in the river is 237,000 as measured at Kalabagh and plotting the curve from the observations in the table below the following results are obtained:—

Area.		H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.
51,875	..	58·5	15·07	781,756	0·29
49,437	..	56·5	14·72	727,713	
45,369	..	52·5	14·02	636,073	or S=·0003
41,283	..	49·1	13·41	553,605	
33,376	..	41·0	11·89	396,841	

Area of curve $\times$ K $\times$ $\frac{8}{24}$ $\times$ 2 = Volume in lake + volume in river.

$$\text{or } 38{\cdot}32 \times \tfrac{2}{3} \times K = 10{\cdot}95 + \tfrac{50}{24} \times 2 \times 2{\cdot}37$$

$$\text{or } K = 0{\cdot}815$$

$$\text{and } K = \frac{1{\cdot}486}{n} \times S^{\frac{1}{2}}$$

$$\text{or } n = \frac{1{\cdot}486}{0{\cdot}815} \times {\cdot}0003^{\frac{1}{2}}$$

$$= 0{\cdot}0315$$

$$\text{and mean velocity} = R^{\frac{2}{3}} \times K = 15{\cdot}07 \times {\cdot}815 = 12{\cdot}28 \text{ ft./sec.}$$

$$\text{Discharge} = A \times V\ 51{,}875 \times 12{\cdot}28$$

$$= 637{,}020 \text{ cusecs}$$

Kalabagh.

For Kalabagh making the same assumption as before regarding the water in the river, the area of the curve plotted from the data below is 2·14 sq. ins.

Area.	H.M.R.	$R^{\frac{2}{3}}$	$A \times R^{\frac{2}{3}}$	Slope per thousand.
29,737 ..	28·61	9·35	278,041	0·5
30,867 ..	29·40	9·53	294,163	or S=·0005
31,819 ..	29·87	9·63	307,517	
32,658 ..	30·10	9·68	316,129	

$$\text{Area} \times K\ \tfrac{2}{3} = \text{volume in lake + volume in river.}$$

$$21{\cdot}4 \times \tfrac{2}{3} \times K = 10{\cdot}95 + \tfrac{58}{24} \times 2 \times 2{\cdot}37$$

$$K = 1{\cdot}57$$

$$\text{and } K = \frac{1{\cdot}486}{n} \times {\cdot}0005^{\frac{1}{2}}$$

$$\text{or } n = \frac{1{\cdot}486}{1{\cdot}57} \times {\cdot}0005^{\frac{1}{2}} = 0{\cdot}212$$

$$\text{and mean velocity} = R \times K = 9{\cdot}68 \times 1{\cdot}57 = 15{\cdot}20 \text{ ft./sec.}$$

$$\text{and discharge} = A \times V = 32{,}658 \times 15{\cdot}20$$

$$= 496{,}400 \text{ cusecs.}$$

DISCUSSION.

Mr. Crump, in introducing paper No. 134 on Mr Gunn's behalf, remarked as follows:—

Mr Gunn's paper, which when proceeding on leave he suggested that the speaker should introduce to this Congress on his behalf, presents for discussion the more technical features of his fuller official report to be found in Irrigation Branch Paper No 32 which has recently been printed and circulated.

The report contains an interesting account of Mr. Gunn's expedition, last summer, to the Upper Shyok River and the Chong Kumdan glacier at its head.

On the 14th of August when the party, after making a survey of the lake, started on its return journey from the head of the Gapshan lake by way of the Dipsang Plain trade route, the glacie was still intact and was completely blocking the valley, but on the party's arrival three [illegible]

[illegible] the volume of the lake at 10,9[illegible],000 foot-acres, and from this known volume he has in Appendix E of his paper calculated for each of five sites the value of the assumed constant $K = \frac{1 \cdot 486}{N}\sqrt{s}$ which enables him to evaluate the peak discharges and mean velocities given in Table 3.

From the point of view of Mr. Gunn's investigation the bursting of the dam occurred at a most opportune time in that it added greatly to the fullness and interest of the data collected by him. The speaker [illegible]

The speaker had little opportunity of discussing his paper with Mr. Gunn, and it is most regrettable in view of the many surprises he has sprung upon them that he is not present to-day to elucidate certain points and reply to the discussion.

Speaking as an independent member of this Congress, the first question he wished to take up is that of the data relative to the Khairabad Gauge at Attock. It will be noticed that the paper presents two independent sets of results for this site. One is based on Mr. Gunn's logarithmic formula on page 58, and the other on the known volume of the lake. In Plate XII, for instance, discharges shown by the small circles are calculated from the logarithmic formula, and give a peak discharge of about 5,11,000 cusecs. For the steady gauges of 27.5 and 28 0 feet which respectively preceded and followed the flood, Mr. Gunn has, however, abandoned his formula in favour of the value of 2,37,000 cusecs measured by the Discharge Division at Kalabagh on the

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17th and 22nd of August, **i.e.,** before and after the passage of the Shyok Flood. The effect of this departure from his formula is greatly to increase the apparent volume of the flood, which, even so, is still nearly 20 per cent less than the known contents of the lake. The higher limit for which Mr. Gunn claims that his formula is reliable is only 3,00,000 cusecs, and the clear implication is that when extrapolated beyond this limit, the formula gives discharges which are too small. To confirm this the speaker had taken the cross section of the Khairabad site which Mr. Gunn used for his calculations of Appendix E, and had worked out the mean velocities for various gauges, by dividing his formula discharge by the corresponding sectional area The result is shown by the full black curve in diagram No. 3A. It is seen that the mean velocity attains a maximum for a gauge of about 32 feet, and then falls off for higher gauges. The compact nature of the section considered renders such a result extremely improbable.

[illegible] entirely [illegible] lischarge [illegible] feet per sec. These values are about 25 per cent in excess of those given by the logarithmic formula The calculation for K on page 71 is, however, made to depend on the Kalabagh value of 2,37,000 cusecs for the steady gauges of 27 5 and 28 0 feet which preceded and followed the passage of the Shyok Flood.

The speaker suggested that it would be more logical to ignore the Kalabagh figure altogether, and to make the calculations consistent among themselves by using the same value of K throughout. Adopting this method, he obtained from the cross section used by Mr. Gunn the following values :—

Mean gauge	=	27.75
Sectional Area	=	28,750 sq. ft.
R	=	35.7
$R^{\frac{2}{3}}$	=	10.84
$A R^{\frac{2}{3}}$	=	3,11,700

Replacing the Kalabagh value of 2,37,000 by $K A R^{\frac{2}{3}}$ the calc[illegible]tion for K becomes :—

$$38.32 \times \tfrac{2}{3} \times K = 10.95 + \frac{100}{24} \times K \times 3.117$$

giving K = 0.872 as against Mr. Gunn's value of 0.815.

This increase in K increases the peak discharge to 6,82,000 cusecs, nearly 34 per cent. greater than given by Mr. Gunn's formula and gives an initial and residual discharge of 2,72,000 cusecs as against 2,37,000 cusecs adopted by Mr. Gunn.

[illegible]an velocities corresponding to K = .872 are plotted in diagram [illegible] It is seen that they differ widely from Mr. Gunn's formula

values. In particular it may be noted that the peak-discharge velocity is now 13.14 as against 9 86 given by Mr Gunn's formula This gives a co-efficient of 0.73 as against 0.55 (suggested by Mr Gunn at page 62 of his paper) for converting surface velocities to mean velocities.

In this connection Lala Nok Chand, now in charge of the Discharge Division, had informed the speaker that his estimate (based on floating-log velocities) of 8,17,000 cusecs for the record 1929 flood on the 28th of August, gave a value of N = 0.043 for an observed surface slope of 0.45 per cent Applying the same value of N to the Shyok Flood he obtains a result of 6,96,000 cusecs which is in very fair agreement with the speaker's figure of 6,82, 000. It must, however, not be overlooked that Lala Nok Chand s first direct estimate of the peak-discharge of the Shyok Flood was 8,41,000 cusecs. This is no less than 65 per cent. in excess of Mr Gunn's formula value of 5,11,000

It will be appreciated that the observational data available for the Attock site is much fuller and more reliable than for the three sites on the Shyok, and if it appeared that he had unduly laboured this question his justification for doing so lay in the importance of bringing to light the great difficulties met with, even by skilled observers working under favourable conditions, of accurately computing the discharge of a large flood of short duration

The most interesting results of Mr. Gunn's investigations are perhaps those presented graphically in his Plate VIII. A part of these results have been reproduced by the speaker in the Diagrams 1A and 2A with the additional further data supplied by Lala Nok Chand for points below Attock, both for the Shyok Flood and for the record flood which followed it a few days later. In Diagram No. 1A are shown three sets of curves The horizontal scale common to all curves gives distances from Chong Kumdan Dam. The broken curves and isolated points show the magnitude of the peak discharges for the two floods. Solid lines indicate the absence of any addition of water from tributary ms. The travel curves show the progress of the mid peak plotted the vertical time scale on the left. The slope of these curves e rate of advance of the peak. With time plotted vertical, increased neans a lower speed of advance The fine black curves are longi-sections drawn through the peaks of both floods. The upper rs to the record flood and the lower to the Shyok. The his curve indicates the general slope of the river bed from tock Above Attock level data is very scanty, but he had extended the slope curve up to the dam by drawing a smooth free hand curve through the few points on the Shyok whose R. L. is known, and in Diagram 2A against, bed slope taken from L. Nok Chand's curve and his freehand extension of it, the speaker had plotted in black the rates of peak travel taken from the Shyok travel curve of Diagram 1A. The points show the mean velocities given in the last column of Mr. Gunn's Table 3.

From the broken curves of Diagram 1A the general inference can [illegible]

[illegible] rate of peak dissipation is much the same for large as for small floods.

With regard to the rate of travel of the peak, it is easy to show that the speed of advance (u) of a steady discharge Q riding on a smaller *steady discharge q is given by the simple relation.*

$$u = \frac{Q-q}{A-a}$$

Where A and a are the average cross sections corresponding to the two discharges Q and q taken over the same reach. In saying this, it must be borne in mind that the several cross sections of which A and a [illegible] intervals, so as to include [illegible] ir contribution to the dis- [illegible] vhere a river valley runs transverse to the rock strata, the existence of numerous lateral valleys [illegible] words, the increas[illegible] smaller value for [illegible] therefore of the me[illegible]

velocity $V = \frac{Q}{A}$ is less than the mean velocity $v = \frac{q}{a}$ and it is found that u is still less than V; while normally V is greater than v, and u is greater than either V or v.

This elementary analysis may serve to explain why in the alluvial reaches below Kalabagh, the rate of advance of the Shyok Flood was slower than the mean velocity of flow, and also why below Ghazighat [illegible] k Flood. Turning [illegible] slightly higher rate [illegible] 1926 than that for the larger flood of 1929.

Turning to Diagram 2A (which deals only with the Shyok Flood of 1929) it is seen that the rate of travel below Attock bears a very definite relation to the bed slope of the Indus Between Sasir and Attock on the other hand, no such relation can be traced. The rates of travel for various reaches range from 8.67 feet/sec. to 15.12 feet/sec. They appear to bear no relation to the general slope of the bed, although this varies from less than 1 to over 8 feet per thousand. The average value is 12.1 feet/sec. which is comparable with the calculated mean velocity of flow of Table 3 for Sasir and Attock and somewhat less than those for Khalsar, Skardu and even Kalabagh.

Referring to Table 3, the general indication seems to be that the mean velocity of flow is independent of the general slope of the bed instead of varying as would be expected with the square root of the slope. It would appear however that the abnormal values of N which Mr. Gunn finds for Sasir and Khalsar result from his having calculated these values from the average bed slopes of Plates II and III instead of from locally observed surface slopes such as was presumably the case for the other three sites considered. The speaker would suggest that if Mr. Gunn had been able to observe local slopes at Sasir and Khalsar he would have found them to have values low enough to yield normal values for N. At page 55 of his paper he states that the flow in floods is extremely turbulent and influenced largely by local conditions Again at page 6 of his official report he says that the bed consisting of large shingle and small boulders is unstable owing to the steep slope; that rapids of considerable length alternate with regions of smooth flow; and that the position of these is constantly changing. From this description it is obvious that the surface slope, (or more correctly the slope of the hydraulic gradient or total energy line), must vary greatly from point to point, and in comparatively quiet reaches must have values very much less than the average bed slope.

In steep river channels this variation in surface slope and hydraulic [illegible] ies. In high supplies, [illegible] The speaker suggest- [illegible] rate of consumption of energy, the evening out is less than is apparent Rapids and bars [illegible]

[illegible]

losses takes place.

Mr. Khosla said :—

Mr. Gunn's highly interesting paper may be divided into two sections :—

(i) Flood prediction at Attock in the event of a burst up at the Chongkumdun or Shyok dam for different lake levels ;

(ii) a study of the conventional hydraulic co-efficient with special reference to the turbulent flow during floods.

As to the quantitative flood prediction, nothing better could be done with the data available and the result given by Mr. Gunn,

From the broken curves of Diagram 1A the general inference can be drawn that the rate of peak dissipation increases with bed slope. Comparing the two lines for the Sukkur Kotri reach, the peak discharge of the record flood is diminished to 76 per cent as against 81 per cent. for the Shyok Flood. In the absence of further data it would appear that the rate of peak dissipation is much the same for large as for small floods.

With regard to the rate of travel of the peak, it is easy to show that the speed of advance (u) of a steady discharge Q riding on a smaller steady discharge q is given by the simple relation.

$$u = \frac{Q-q}{A-a}$$

Where A and a are the average cross sections corresponding to the two discharges Q and q taken over the same reach. In saying this, it must be borne in mind that the several cross sections of which A and a are the means [illegible] intervals, so as to include [illegible] ir contribution to the dis- [illegible] vhere a river valley runs transverse to the rock strata, the existence of numerous lateral valleys and ravines would have a marked effect in increasing the areas inundated in a big flood. Or again, in alluvial tracts, the extensive lateral spreading in high floods would add greatly to the average area of cross section without contributing greatly towards increasing the discharge. In other words, the increased wetted perimeter may, in certain cases, result in a smaller value for a large than for a small discharge of the H. M. R. and therefore of the mean velocity In such cases what may be called the mean velocity $V = \frac{Q}{A}$ is less than the mean velocity $v = \frac{q}{a}$ and it is found that u is still less than V; while normally V is greater than v, and u is greater than either V or v.

This elementary analysis may serve to explain why in the alluvial reaches below Kalabagh, the rate of advance of the Shyok Flood was slower than the mean velocity of flow, and also why below Ghazighat the Record Flood [illegible] than the Shyok Flood. Turning [illegible] lso explain the slightly higher rate [illegible] smaller flood of 1926 than that for [illegible]

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[illegible] this variation in surface slope and hydra[illegible]

[illegible]

finer material carried in suspension. It would appear in fact, from the results now before them, that these relatively quiet reaches do not greatly vary, in regard to their mean velocities, from Sasir to Attock, and that the channel adjusts itself to an increase in general bed slope by the more frequent formation of bars and rapids, where the greater part of the energy losses takes place.

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As to the quantitative flood prediction, nothing better could be done with the data available and the result given by Mr. Gunn, will be *of*

lasting value in spite of some of the assumptions which he himself characterises as "bold in the extreme."

Mr. Gunn has brought out some very important points such as the 28′ cross slope in 1929 flood at the Khalsar Gauge site and the wide variation in the flood heights of 1926 and 1929 floods, the range being from 8·27 to 47·19 ft., following no definite order of distances.

The method of working from the storage volume of the lake to obtain peak discharges and gauges is highly ingeneous and a valuable contribution for future flood investigations.

But when he proceeds to the analysis of the co-efficient "N" and the factor applied for reducing surface to mean velocities on the basis of the available data some of the assumptions appear 'too bold'. Whereas, it

way in focussing attention and effort towards a clarification of our ideas about the fundamentals.

On page 55 Mr. Gunn has rightly "not attempted to draw a longi-
levels" but in his calculations for
"S" based on low water levels
id III Again, he has not taken
local values of S at sites of sections but has taken the mean of 12 miles at Khalsar gauge and of six miles at Sasir Brangsa. In view of the

the flood.

Mr. Gunn has placed too much-faith in the logarithmic formula of page 58 for Khairabad gauge but the assumptions made therein must be remembered, to give it true weight. For the Khairabad gauge he has taken discharges observed at Kalabagh some 90 miles downstream and has allowed for a time lag which can at best be taken as hypothetical. His peak discharges are extrapolated beyond the range of observations. With the best of results, this equation can only be an approximation and the deductions therefrom can be an indication as to the accuracy of other data and not a definite check

On page 60, Mr Gunn has taken Manning's formula as a basis for a study of co-efficients in turbulent flow. He has assumed

$\frac{1{\cdot}486}{n} \times \sqrt{S} = K$ a constant without justifying his assumption.

On page 62, he says that "as may be expected the co-efficient K is not a true constant for the whole range of the flood at any site but varies with the degree of turbulence." Reference is here

invited to page 243—246, Vol IV of the Miami Conservancy District publication "Calculations of flow in open channels", wherein the relative merits of the Manning formula as against Kutter's have been discussed. This formula gives consistent results for values of H. M. R up to 4'. For higher values the slope largely affects the results. The 'C' of Chezy in $V = C\sqrt{RS}$ is the same as $\frac{1.486\ R^{1/6}}{n}$ of the Manning formula. Plotting C as abscissa and R as ordinate, it is at once apparent (Figs. 61 and 62) that there is increasing divergence between values of C as derived from the two formulae. For n = 030, the two agree for slope of 10 ft. per ‰ For n = 010, the two agree for S = ·000025. For slopes considered in this paper the variation in value of C by the Manning and Kutter's formulae is not large, when n = 0 030, but for flatter slopes or for higher values of 'n' like 0·08 this variation may be considerable.

For purposes of Table 3, Mr Gunn has made allowance for the normal river supply before the flood came on This is, however, a very uncertain factor. In connection with the flood investigation for the Haveli Project, the question of what to accept as the normal supply for purposes of comparing the foot acres passed at different sites between the flood peak and the normal, is offering some considerable difficulty. A small mistake in arriving at the correct normal will throw out the value of K and consequently of N

$$K = \frac{\text{Volume of lake}}{\left\{\begin{array}{l}\text{Area of time dischage curve}\\ \text{at any site between peak and normal}\\ \text{river.}\end{array}\right.} = \frac{\text{Volume}}{\Sigma A}$$

Supposing ΣA to be exaggerated, K will be diminished.

Since $n = \frac{1{\cdot}486/}{K}$, therefore 'N' will increase.

For Sasir Brangsa and Khalsar, Mr. Gunn has ignored the normal flow altogether. Perhaps his local knowledge justifies this step. But if there was any discharge passing, that volume if deducted from the volume of the lake, will increase K and therefore reduce 'N'. The high co-efficient of 0·1651 and 0·0872 may at least in part be due to this omission.

In view of the assumptions referred to above it is not possible to place implicit reliance on the peak discharges or the values of 'N' deduced. The mean velocities will be effected in consequence.

The speaker fully agreed with Mr. Gunn in his contention that the co-efficient of 0·9 used to reduce surface to mean velocities is very doubtful but the extremely low value of 0·55 deduced by him cannot be accepted

as a nearer approach to truth as the fundamental assumptions lack justification.

Mr. Gunn's paper also helps to remove the general misconception that the peak discharge of a flood at one place is necessarily the same lower down irrespective of the distance. The peak discharge decreases as the flood travels down, the duration increases but the foot acres passed at each site above the normal are very nearly the same. Investigations in connection with the record flood of 1929 support this fact in the cases of Indus, Jhelum and Chenab.

Mr. Montagu had no wish to belittle Mr. Gunn's achievement in sounding the Lake Gapshan but he had certain criticisms to level at the calculations for discharge.

2. There were at least three classes of flow, *viz.*, the viscous (true stream line), turbulent (silt bearing): mechanical turbulence, for want of a better name (flow in which part at least of the "slope" is due to falls and the *mechanical* turbulence that results).

The slopes quoted as "mean slopes" on page 54 by Mr. Gunn emphatically belong to the last class of slope and certainly are not normal slopes such as are applicable to Manning's formula for "normal" flow

3. Mr Gunn appears to have taken no account of the important effect on flood flow of the velocity reaching the "Minimum Energy" point Should this state of affairs occur then any obstacle will result in considerable heading up which will accelerate the approach of the flood but retard the peak

That this appears to have occurred is evidenced by the Table I on page 56 of which extracts are now given comparing the two floods of 1926 and 1929.

	Skardu to Bunji.	Bunji to Attock.	Total.
1926 ..	8 hours.	30½ hours	38½ hours.
1929 ..	14 hours.	29 hours	43 hours.

The smaller flood has definitely taken longer than the larger.

4. If Mr. Gunn confined himself to a simple statement of volumes in the Lake Gapshan on given dates, the only question at issue would be the accuracy of his observations, but his attempts to confirm his observations by other evidence leads to contradictions

[illegible] "normal" inflow? Does Mr. Gunn
of 0·9 feet a day means 328 5 feet a
ear ago (1928) of 15,850 and the level
ven level of 15,885 at which the lake
burst.

Either Mr. Gunn's estimate of the volume of the lake is wrong, or his observations and deductions about the average inflow are inaccurate.

5. Mr. Gunn's attempt to co-relate the inflow into the lake with the temperature and discharge curve at Khalsar is neat, but leads to more inconsistencies. From 1st to middle of August, the temperature discharge curve indicates a flow in the Shyok of about 40,000 acre feet per day. On page 56 Mr Gunn intimates an inflow to the lake of 6,580 acre feet. He saw no reason why the two discharges should be in any way co-related; however 6 580 is 16 per cent of 40,000.

But this gives a rise during the period of *biggest inflow* of 0·55 feet per day against the 0 9 feet arrived at by different observations.

Turning now to Table II on page 57 and converting the cusec discharges into acre feet it is found:—

	Khalsar.	Gapshan.	Per cent
June .	60,000	5,000	8 3
July ..	1,320,000	115,000	8 7
August ..	2,100,000	183,000	8·7
September	720,000	63,000	8 7

Why should Mr Gunn suddenly vary the percentage from 16 per cent to 8 per cent ? It follows that a trifling error in the per cent. relation will result in a considerable error in the estimate of Lake Gapshan volume, even if it is assumed (which the speaker did not admit) that there is any comparable relation at all

6. Another speaker will deal with the logarithmic equation on page 58 so he would pass directly to the application of Manning's formula to evaluating the discharges, on page 60.

In Manning's formula S, the slope is that of the total energy line and represents the loss due to friction arising from the periphery and not from energy lost in standing waves and genuine mechanical turbulance.

It is not even the slope of the surface unless the surface and T. E. line are parallel The slope of the surface in flood is therefore useless for the purpose. It is even more useless to take the slopes mentioned on page 54 which appear to be purely arbitrary averages of differences in levels.

7. The assumption that $\frac{1\,486}{N} \times S\,\frac{1}{2}$ remains constant is of course fundamentally incorrect.

The Table III on page 61 is instructive in this respect.

(i) Generally speaking, Kalabagh is the only site where Manning's formula is in the least degree applicable.

(ii). At Attock the slope appears definitely to be too low and heading up appears to have taken place above.

(iii). The other slopes are far too high and indicate that falls and mechanical turbulance existed. This is borne out by the resulting N. N as such cannot possibly vary from 0·1651 to 0·0212. *Clearly the slope taken in the first cases is excessive and so N must work out too big to compensate the value of K.*

(iv). Again it appears improbable that the velocity should *rise* from 12 f. p. s to 15 f p s as the slope falls.

(v). The one exception to this is the velocity at Skardu. Cross sections at site were not given, so the speaker was unable to look for a physical explanation.

He suspected an arithmetical error, so looked through such figures as were given

On plate XV compare stages 2 and 3.

[illegible] ...iously there is an observational *error* [illegible] and stage 3 is 44,000 square feet *how* [illegible] respectively?

Clearly the Skardu observations and consequent calculations are definitely wrong

8 Mr Gunn draws a misleading conclusion in suggesting the variation in N is due to turbulance It is due to his assumption and his application of Manning's formula being unjustified.

9 The speaker endorsed Mr Gunn's suggestion for further investigation and defined the problem as an enquiry into flood transmission by waves which could be carried out in the laboratory by measuring the rate of rise and time lag of an efflux from a measured tank, due to the influx of a known discharge

L. Nok Chand, supplied a written communication in which he stated —

That the Author expected someone to carry out further investigations of correct co-efficients for mean velocities. Though not impossible, this problem is practically difficult for high floods at places like Attock and Kalabagh At these places even a motor launch will not be able to remain steady for accurate measurements of mean velocities I tried to observe mean velocity at Attock by lowering the meter from the bridge, but the urbulance and the high velocity would throw up the meter to surface and would not allow it to sink although the weight attached to it was 27 lbs

[illegible] flood that even [illegible] for these sites during floods

The reduced datum levels of water surface for Skardu Bunji and Chilas are not given by the Author, and it is not possible to get any accurate [illegible] slope for the reach Sati [illegible] given as 19 feet per mile [illegible] assumed to be the same [illegible] of 28 feet in 2,000 feet

width is nearly 4 times the longitudinal slope which seems unlikely ... rved. ... that

The Author says on page 65 that flood marks at any one place noticed in one year cannot be taken as a g ... This is because there are so m ... the Shigar. ... eing 12 ... being ... rly the same time as those from Khalsar.

The Author has given a discharge curve for Khalsar. But he does not supply the details of his observations to show how the mean velocities were arrived at, or whether they are all based on his hypothetical coefficients Since the Author has fixed a gauge at Khalsar, it would have been better if he had calibrated this gauge, and given a comparative curve of Khalsar and Attock gauges.

In working out his logarithmic formula the Author has based his calculations on a curve of Attock gauges plotted against discharges at Kalabagh which is 100 miles downstream. This curve when plotted differs from year to year and any mean line as a fairly accurate guide cannot be chosen The Author has not said what time-lag he assumed between Attock and Kalabagh which in itself is very variable.

The discharges taken for Kalabagh are only for a range of discharge up to three hundred thousand cusecs and it is not safe to exterpolate a curve for nearly double this supply Nor can the formula be considered accurate for supplies beyond the range of observations when it involves so many uncertain factors

Local heading up at Attock taken as 5 feet by the Author cannot always remain constant. The amount of silting or scouring in the river bed at Attock at any period is a variable quantity whose value cannot be stated without actual measurement But Attock is simply a gauge site and no soundings or discharges are observed by the Discharge Division at this site. Any arbitrary assumption about the bed at Attock will render the formula inaccurate and make its utility very doubtful.

The Author does not give the maximum lake level of which he found traces available ... record flood at t ... observed at Atto ... Working from t ... charge was nearly 6,96,000 cubic feet per second against the 5,11,000 worked out by the Author's formula.

The future damming up of the Indus supplies may not be at place of last year and may take place in some other tributary such as Nubra or Shigar which have glaciers of very large

though not yet explored. If so, a gauge in the Gasphan lake will be valueless, and all the warning arrangements from Khalsar of no avail.

Mr Gunn in replying to the discussion, said—The Author wishes to thank Mr Crump for the care he has given to introducing the paper and to criticising the results set forth in it.

It may clear matters somewhat if it is again emphasised that while the figures are correct so far as it lay in the author's power to observe them, the data are not sufficient to warrant any definite conclusion being accepted finally.

In regard to the Kalabagh discharge formula it was the best the Author could derive with the data at his disposal and can only be applied to a river bed free from silt Hence the acceptance of the observed discharges before and after the flood. It must also be remembered that the volume of the lake is only an approximation, and this combined with the absence of any positive depth measurements at Attock, led to the acceptance of the approximate figures in the table.

Mr. Crump has taken the study of the gauge discharge curve at Attock a step forward and produced a much more reasonable co-efficient for reducing surface to mean velocities, but in doing so he produces also the result that the discharge of the Indus was 2,72,000 cusecs instead of the 2 37,000 reported an excess of over 10%. The question is still open for further research.

Mr Crump's study of the movement of the flood below Attock is interesting and worthy of close attention.

Mr. Khosla's kindly criticism calls for little comment. The Author would only remark that owing to the nature of the flow all hydraulic flow formulae are equally inapplicable and Manning's seemed the simplest and was adopted.

Mr. Montagu appears to have misunderstood some points in the paper. The particular " normal inflow " might more properly have been called inflow to be expected in normal weather. Obviously the rate of rise depends on the surface area of the lake and decreases for the same discharge as the water level rises

The Author would also point out that he was not attempting to confirm his observations, but to see how far the reports received tallied with the observations made

Mr Montagu's difficulty regarding the sudden change in percentage of discharge may be cleared by a reference to table 2 where it can be seen that the Khalsar discharge is in cusecs and not in foot acres.

The author is much obliged to Mr Montagu for pointing out the apparent source of error in the Skardu observations, he will investigate the matter on his return to India He had also taken much time checking the arithmetic.

L Nok Chand's remarks call for no special reply. The Author would merely remark that his statement regarding flood marks on the right bank was meant to refer to the intermediate stages of the flood and not to the maximum.

PAPER No. 135.

EROSION IN THE PUNJAB HIMALAYA AND ITS PROBABLE EFFECT ON WATER SUPPLIES.

By

L. B. Holland and H. M. Glover, I. F. S.

The subject of erosion consequent on the disappearance of forests in the outer Himalaya is engaging the attention of the Punjab Government, and it is thought that you may be interested to learn the views of Forest Officers on this very important subject.

Two technical papers have recently been published, 'Denudation of the Punjab Hills,' by B. O. Coventry, I. F. S., Indian Forest Records, 1929, and 'A Report on Denudation and Erosion in the Low Hills of the Punjab,' by L. B. Holland, I. F. S., 1928: the latter as the result of a special enquiry in 1927-28. In this paper the general aspect and extent of erosion and its probable effects on water supplies will be discussed, and in order that the problem may be easily understood some description will first be given of the geographical, climatic, geological and other factors

The Punjab consists of low lying alluvial lands in front of the

exception of the Indus and Sutlej which rise in Thibet, lie either in British territory or in States under the political control either of the Government of India or the Punjab Government

The rivers are tapped by canals where they enter the plains and again lower down where drainage from the country below the head works has

lting snow ; and in the monsoon the

tion of

pproxi-

Year 1926-27—Cusecs at Bakhra.

October	7,000
November	5,500
December	4,500
January	3,750
February	4,000
March .. .	4,250
April	5,000
May	8,500
June	20,000
July	50,000
August	75,000
September	25,000

Maximum flood August 10th, 150,000 cusecs.

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[illegible] of India or the Punjab Government

The rivers are tapped by canals where they enter the plains and [illegible]

[illegible] the water escapes to the sea and is lost to the Province. Some approximate figures of discharge of the Sutlej river may be of interest :—

Year 1926-27—Cusecs at Bakhra.

October	7,000
November	5,500
December	4,500
January	3,750
February	4,000
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Maximum flood August 10th, 150,000 cusecs.

Rainfall.

The rainfall is profoundly affected by the summer monsoon. During July, August and September the moisture laden winds from the Arabian Sea and from the Bay of Bengal strike the barrier formed by the Himalaya and the clouds drop the greater part of their water contents, and as they pass in succession over the inner ridges more and more water is dropped until the great Himalayan range is reached where the last rain is precipitated. Beyond this barrier very little rain falls and the country is dry and sterile. In the spring and autumn little rain falls for weeks on end. In the winter snow falls in the inner hills and accumulates to depths of several feet. In Tibet there is no rain during the spring, summer and autumn and in the winter snowfall is less than in the inner hills Some figures may be quoted :—

[illegible]

snow : Poo 200 miles by road from Simla has a rainfall of only 14 inches. Rainfall varies with elevation, and whereas the tops of the hills are often moist the valleys are dry and sterile. In the inner Himalaya the streams are glacier fed and towards the Thibetan border winter snow and glaciers form the sole sources of supply of water to the streams.

Geology.

A sketch of the geological features must of necessity be brief and only a short general account is given in order to render this paper intelligible. The main mass of the Himalaya consists of granite and crystalline rocks Spiti contains thick beds of fossiliferous limestone and sedimentary strata: the inner Himalaya consists of crystalline rocks and metamorphosed sedimentary strata twisted and contorted till all traces of their organic contents have been lost All these formations are more or less stable and the hard rocks are not liable to displacement The mountain ranges of the Himalaya were formed by the effects of pressure from the north which caused their upheaval when confronted with the buttress formed by Hindustan. In front of the rising Himalaya were deposited in shallow sea conditions the Tertiary sandstones and clays which in their turn took part in the general uplift and were folded and bent and now occupy the zone of the outer hills from Sabatu to Hazara. In front of and on these strata were deposited detritus and the Siwaliks form a range in front of the Himalaya consisting of soft friable sandstones and pebble beds which in their turn have been folded and elevated. The plains consist of vast alluvial sediments deposited in front of the Himalaya.

Effect of forest on rainfall.

The rainfall is affected by the geographical position of the locality and is due to causes on which forests have little effect. It is thought that forests increase local precipitation but the evidence therefor is somewhat vague and indeterminate.

Effect of forest on run off.

A forest consists of trees or scrub and below the trees is a mass of

... springs, many of which are permanent. Only when the surface soil is supersaturated does the water run over the surface. Thus rain which falls during the summer monsoon emerges some weeks or months later from springs and replenishes the autumn and winter supplies of the rivers. The soil is retained *in situ*: the water in forest streams is clear and does not contain much sediment in suspension. Far different is the effect of rainfall on barren slopes. The soil is thin and hard, and rain when it falls runs over the surface soil and enters the streams during the monsoon.

As forests disappear more and more water enters the streams which constantly broaden their channels which are insufficient to carry the largely increased supplies. Floods occur which increase rapidly in

... August 1928 in the Chenab and Jhelum rivers and the floods of 1929 in the Jhelum and Indus rivers to quote only very recent history.

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to b
that the intensity of floods is rendered greater by the disappearance of forests and it is of interest to examine the sources of supply of the rivers and the condition of forest growth and soil covering in their catchment areas.

Conditions in Catchment areas.

We may for the purpose of this note divide the Himalaya into three broad belts—

(*a*) The zone bordering on Tibet,

(*b*) The inner Himalaya, and

(*c*) The outer Himalaya.

(*a*) The zone bordering on Tibet.

... country is desolate in the extreme and only where water ...

been built is cultivation possible. A few briars and junipers occur at wide intervals; carragona and wormwood bushes take the place of grass, but usually there is nothing but bare precipices and rock screes. At high elevations there is sometimes a little grass and in side valleys some forest. Vegetation here is scanty and has little effect on the water supply.

(*b*) The inner Himalaya.

As the region of monsoon rainfall is approached vegetation appears and forests, which at first are confined to the side valleys, gradually cover the uncultivated slopes. To the south of the great Himalayan range vegetation increa [illegible] belt; above and [illegible] which are fired [illegible] no doubt that the whole country was formerly covered with forest and [illegible]ng [illegible]]as [illegible]

In the forests the soil is deep and moist and when the trees were cut and burnt magnificent field crops were raised, but at the end of three or four years the soil had largely eroded and had become sterile. The land was allowed to lie fallow for many years until a fresh crop of bushes or trees again covered the ground and was burnt for manure.

Below the main forest belt the ground was terraced and field crops were raised; but as the forest disappeared the soil became thin and sterile and capable only of supporting a thin crop of grass. Over large areas in the Sutlej valley there are remains of cultivated fields which are now incapable of carrying field crops except in a few favoured places where the soil has been retained. The springs have dried up and no longer is there sufficient water for irrigation.

The more valuable forests have been demarcated and worked for timber for export, but as the price of timber in the plains rose some Indian States took advantage of rising prices to cut down their forests of which the Suket State in recent years forms the worst example. During the war the Suket forests were cut down till in 1919-20 the Commissioner asked for them to be inspected, every timber tree in accessible areas was felled or marked for felling, and although a temporary check was given to exploitation in 1920 timber has since been extracted; the fires of 1921 ravaged the forests and little or no timber can now be available for future generations.

Fires both accidental and malicious are always to be feared and in 1921 in connection with the general propaganda against Government hundreds of thousands of acres of forest were burnt to the great depletion of the economic resources of the country. In 1924 floods occurred in the east of the Province and it is thought that their intensity was aggravated by the destruction of forests by fire in 1921.

Fortunately in the inner Himalaya the geological structure of the

to prevent serious erosion and some water is retained.

The conditions of the inner Himalaya are on the whole satisfactory and no special action is called for provided always that the present forest policy is adhered to and that fires and shifting cultivation are kept in check. In the Indus catchment area the deodar forests of transborder states have been cut over heavily in recent years, but the country has lately been brought under British influence and it is hoped that the forest will be preserved

(c) The outer Himalaya.

In the outer Himalaya conditions are very bad indeed : the forests have largely disappeared and all vegetation in the village waste is subject to very heavy grazing by both local and migratory flocks which are slowly but surely destroying all tree and bush growth. For details regarding the disappearance of the forests you are referred to Mr. Holland's Report on denudation and erosion, 1928.

Throughout the outer hills forests have either entirely disappeared from the village waste lands or are in danger of extinction Tracts of land are still scantily covered with trees, but one feature is common to all forests such as are not demarcated as reserved or protected forests under the control of the Forest Department, namely the complete failure of reproduction of any species except the more xerophytic bushes, such as *carissa, dodonea* and *adhatoda vasica* which are not liked by sheep and goats. Over wide areas the destruction of the forest growth has laid bare the soil ; the grass itself has disappeared and the productivity of the locality has most seriously diminished.

On the Tertiary formations the hard sandstones interbedded with clays prevent the formation of extensive landslips ; but surface erosion

It may be thought that we are exaggerating the evils : we know that we have understood the case and will end with a quotation dated 1877 from the Punjab Land Administration Manual, paragraphs 728 to 730, concerning the Hoshiarpur *chos*.

" 728. Effects of denudation of Siwaliks on cultivated lands in the plains.

A generation later the effect of the denudation of the low hills, which inevitably resulted from the policy then adopted, on the rich Siwal tract of Hoshiarpur and Jullundur had become so great that the matter was forced on the attention of Government. The Deputy Commissioner Mr. Coldstream, and the Conservator of Forests, Mr. Baden Powell united on urging the necessity of prompt remedial action, and the Commissioner of Jullundur, Mr Arthur Brandreth, strongly supported them.

729. Mr. Brandreth's presentation of the case.

His graphic description of the effects of neglect is worth quoting :—

"The lower Siwalik * * * * is a long low range of [illegible]

[illegible]

lord of the manor, and not made over to the peasantry, these hill slopes [illegible]

[illegible]

the Rajas or to their successors, the Sikh kardars, but it yielded a sort of cover for game, and was consequently generally protected; and as the towns were not then very wealthy, and peasantry had hard enough work to produce the heavy revenue then demanded there was little demand for fuel, and few persons with leisure to cut it

* * * * * * *

"The stunted brushwood had, however, one great value. It covered the sandy soil by its roots and by the grass which grew in its shade. The cool air from the shaded hill-side arrested the passing clouds and produced a constant and almost regular rainfall, which, checked by the leaves of the brushwood and grass, poured down the hillsides at a gentle pace, and, bringing with it all the soluble products of the decayed leaves and grass, spread its wealth-laden waters over the plains below, which thus became so renowned for their fertility as to be known as the garden of the Punjab

"The scene now is far different.

" * * * * * * *

"The hillsides were divided among the villages located on the hills, and the whole brushwood and minor forests declared to be their property village common open to every one.

"With the introduction of English rule, towns increased, wealth and property abounded, and the cessation of the continual demand for forced labour created a class of labourers with abundant leisure, and in search of employment. With the increasing wealth arose increased wish for comfort, and a large demand for firewood of all sorts consequently

soon sprung up, and the unemployed class found the brushwood and low jangal of these hillsides a mine of wealth open apparently to every one. With our large public works and railways the demand increased still more, and the hillsides were consequently in a few years stripped of everything that could by any possibility be used for firewood. Where the distance from the towns was too great the still more destructive char- [illegible]

[illegible]

them some little sum for the rights of cutting and the charcoal burners generally paid Rs. 2/- or Rs 3/- for a year's license They could not be expected to consider the future loss to their children, still less to care for the villages below the hills, which were slowly being ruined.

[illegible]

When, owing to the increasing pressure of the clouds, rain does at last fall * * * The condensation produced by its fall on the heated soil produces * * * a great downward rush of the heavily laden upper air, and the * * * late rain soon [illegible]

[illegible]

retain its moisture for a long period. But gradually the tale became very different. Constant reports of deteriorated crops and distressed villages and tenants unable to pay their revenue replaced the uniformly prosperous report of former days: traffic and trade was checked by the great development of these vast sandy beds, which intersected all the main roads: and further demands for remission began to pour in from villages beyond the action of flood, but whose fields were being buried by the masses of dry sand brought from these torrent beds by the windstorms of the hot weather. Nor was the injury confined to the agricultural peasantry only. The increased volume of waters thus suddenly brought

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down soon carried away the bridges sufficient for former times and compelled a speedy extension of "waterways" and further expensive bridging both on the Grand Trunk Road and the Railway, and when even these proved insufficient the waters submerged the country far and wide. * * * *"

730. Results of delay in taking action.

The picture is highly coloured, but it can hardly be said to be exaggerated. Soon after in reporting on the assessment of the Hoshiarpur tehsil Captain J. A. L. Montgomery pointed out that, owing to the destructive action of the *chos* or sandy torrents issuing from the Siwaliks, cultivation had decreased by 12 per cent. in 30 years.* As we shall see, action was greatly delayed, and things went from bad to worse. In 1897 the Financial Commissioner wrote :—

"During the last period of ten to twelve years on account of the action of the *chos* in Hoshiarpur and Jullundur 16,650 acres of land have been converted into *cho* beds, or have totally lost their productive power, while 23,260 acres in addition have been damaged. Government has remitted Rs 11,855 land revenue, and has in addition suffered or is about to suffer by reductions in the rent rolls of the two districts an annual loss of Rs 34,719 land revenue, while the people have lost at a low estimate over 20 lakhs of rupees in the market value of their lands."

The *chos* increase in size every year despite remedies provided by the partial application of the *Chos* Act 1900 ; the water level is sinking in the Hoshiarpur, Jullundur, and Ambala Districts and enquiries are now being made by Irrigation Specialist Officers as the fertility of large tracts is endangered This apart entirely from the danger to canals and the shortage of winter supplies in the Punjab rivers

Summary of the causes of the recent disappearance of the forests.

Previous to the British occupation the Punjab was in a very disturbed state and life and property were unsafe. Each little hill baron lived in his castle and his people pursued precarious occupations within the enclave of the state protected by the troops, and raids and fighting were common No one could wander far afield without armed protection and the migrations of nomadic flocks were by no means so extensive as they are at present To quote from Lyall's Land Revenue Settlement of the Kangra District 1865-1872 "I have heard old shepherds say that down to British rule it was like running the gauntlet to convey a flock across the low country to its 'ban' (winter grazing ground). Every petty official or influential landholder tried to exact something as the flock passed him a mild man easily daunted had no chance, and the *gaddis* picked out their ugliest customers for the work."

* The action of *chos* is not purely destructive. Far away from the hills after the heavier sand has been dropped, the deposits they spread are often very fertilizing. But wherever the hills from which they run are denuded of vegetation and consist of sandstone rocks, loss must far exceed gain."

With the peace and prosperity brought by British occupation not only did local flocks increase but they wandered farther from the homestead and literally ate their way through the forest a superimposed burden was and still is the grazing and browsing of nomadic flocks During the summer they graze on the luscious pastures of the high hills whence during the autum ... ow and spread over the ... left in a constant endea ... e again enjoy the luxuriant pasturage of the high hills There is not enough for these flocks to eat: *gaddis* from Kangra with numerous flocks of sheep and goats, graziers from Kanawar and the high hills and Gujars with

sequences of a weak forest policy on the destruction of natural resources.

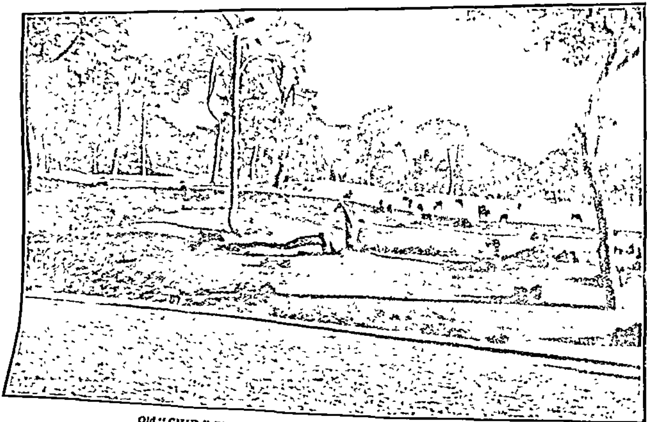
The Rajas had regarded the forests as their own special property and prevented encroachments thereon and grazing therein as interfering with their sport as a consequence the forests were intact when the British first occupied the Punjab The first British land revenue settlements handed over such areas to the villagers as *shamilat*, or village common lands, and as the villagers realised that they now had rights in lands from which they had previously been excluded each man endeavoured to gather what he could for his own and reaped a present advantage from the sale of firewood to the nearest cantonment or town which sprang up shortly after the land was conquered, and peace prevailed

Remedies.

The means to be adopted are the limitation of flocks and herds to the capacity of the country side, the introduction of systematic pasture management and the preservation of the village waste and the forests from abuse. Early and serious steps must be taken to foster and preserve from destruction the scanty remains of the once extensive forest

Proposals have recently been made for dams below catchment areas in order to increase the winter water supplies of the rivers these dams can only be constructed at vast expense and we think we will recognise

ing works made by man are expensive, are mere palliatives and do not remove the disease itself; we must look farther afield and seek our remedies in a more suitable management of the waste lands of the Province.



Old "CHIR" Pine Forest, Heavily *Grazed*, with on young seedlings.

Nadaun Jagir, Kangra District.

The second was to cross the river as soon as possible and to follow

desperately contouring the outer features, thus getting away from the objective.

Immediately after leaving Guler and running through extremely ... ork, the line ... nga at mile ... s from the gorge on to comparatively easy country.

At mile 52 another partial descent, involving further difficult location work, was found necessary in order to negotiate the crossing of the Bathu Khad (mile 53), an important tributary of the Banganga. Here again, full use was made of the grade on the descent and by the use of 100 feet ... the river.

In easy country, and still rising, the alignment follows the left bank of the Daulatpur Nullah until it meets a massive conglomerate ridge which, running in an easterly to westerly direction, effectually blocked all efforts to get round; a second and somewhat longer tunnel had to be accepted. Once through the ridge a short fall brings us to Kangra station site at mile 59.

Section Kangra to Palampur.

... lying to the ... ne drops to ... ry difficult ... something over 200 feet.

From here the valley opens out considerably, and it was found ... reduce the ... which have

... 61 8 The ... merate bluff ... ance it was thought that owing to the danger of slips occuring, the alignment along the cliff would not be feasible, and to avoid this a double crossing of the Banganga had been proposed. On closer investigation it was found that the conglomerate was both compact and well consolidated, and it was considered that the money thus saved justified the risk being taken. Results have entirely justified this decision.



"CHIR" Forest on friable sandstone formation—Erosion commencing.
Nadaun Jagir



Typical Scrub Forest closed to grazing.

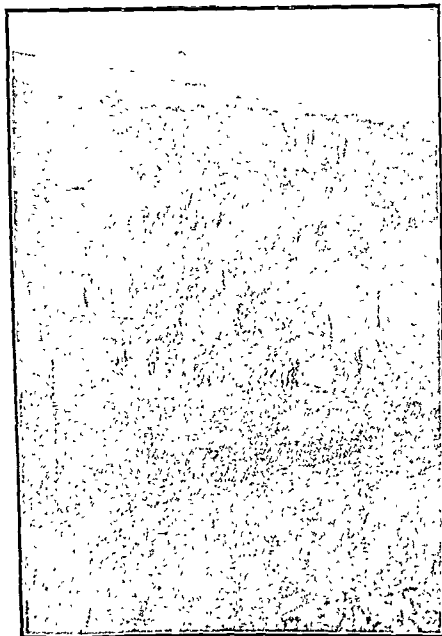
Kangra District.

Photo, *Aggarwal*, 1929.



Scrub Forest—Trees lopped by Gaddis for fodder—Erosion shown in background.

Kangra District.



Scrub Forest—Heavily grazed—Erosion well advanced.
Kangra District.



Scrub Forest—last stage of erosion—Villagers protesting against proposed closure to grazing.

Kangra District

DISCUSSION.

Introduction.

Mr. Glover introduced the paper and referred to the opening address of His Excellency the Governor in 1929, in which he suggested that it might be necessary for Engineering Officers to be associated with Forest Officers in order to devise means of checking erosion

Erosion had increased greatly in the last eighty years and was due largely to the destruction of the forests by herds of sheep, goats and buffaloes, which had multiplied owing to the peace and security brought by the British occupation He dealt with the evidence afforded by history and quoted from the Kangra Gazetteer showing that in Shah Jahan's time dense scrub forests had covered the foot hills in the neighbourhood of Mirpur but had now largely disappeared. He introduced Mr. Holland who had wide experience of erosion in the outer Himalaya.

Mr. Holland in opening the discussion made the following remarks :—

"Since I toured the low hills of the Punjab in 1927 and 1928 from Attock to Gurgaon to report on the erosion and denudation I have been convinced that the time is rapidly approaching, if not already arrived, when the ever increasing destruction of the vegetation, not only in the forests but also throughout the village waste, is bound to threaten your canals.

I believe the canals are threatened in two ways—

first, by ever increasing floods in the rains and

secondly, by steadily decreasing supplies in the rivers during the cold weather.

Some of you may not have considered the effect of well covered hills on the run off.

I would compare a well covered hillside to a bungalow with a thatched roof. The roof absorbs a very large quantity of rain and after the rain is over it goes on
hillside absorbs the ra
gives out the water
a high sub soil water
there is too a steady drainage into the beds of the rivers.

A denuded hillside resembles a corrugated iron roof. The rain runs off in floods and the ground a few hours later is dry. Hardly any soaks into the soil.

People are inclined to look on forests as inexhaustible but their destruction is only too easy and once destroyed it may take generations to replace them.

You cannot plant up a denuded hillside with useful trees, you have to begin with a poor form of shrub growth and as the soil conditions very slowly improve you may be able to introduce a better form of vegetation.

You have only to consider the Hoshiarpur and Ambala Siwaliks which in 1854 were well covered with forest but which 20 years later were naked. To-day the conditions are not much better. Certainly this is so in those parts which drain into the Sutlej and Beas.

While mentioning Hoshiarpur and Ambala I would suggest that the shrinking of the water level in the wells in these districts and Jullundur is directly due to the denudation.

These hills used to absorb a very large quantity of water for the chos in 1854 are said to have been well defined stream with deep beds but to-day they are sandy wastes.

To give you some idea of the amount of water which comes off these low hills I would refer you to the superpassages over the Sirhind canal at Budki and Siswan.

The Budki passage is about 10 miles from the foot of the hills. It is 395 feet wide and 14 feet high. The following floods are recorded :—

1914	..	31 floods maximum flood	7·5 feet.
1925	..	31 floods maximum flood	8·3 feet.
1926	..	25 floods maximum flood	7·5 feet.
1927	..	21 floods maximum flood	10·4 feet.

That is to say a volume of water 395 feet wide and 10½ feet deep. The duration of the flood is not recorded.

The Siswan passage is 250 feet wide by 10 feet deep.

In 1916, 1921 and 1927 floods overtopped the sides of the superpassage.

What sum you have had to spend on training works owing to disforestation of the hills I do not know.

During my tour I saw a very large area of country which does not affect any canal but does affect roads and bridges and as I had to report only on the Punjab hills I was not able to inspect the low hills of Poonch, Jammu, Chamba, Mandi, Suket, etc. I have however seen a certain amount of these areas at different times and I believe conditions there are every bit as bad as in the Punjab.

To take some of the areas which affect the canals, for example the Kangra Valley and Gurdaspur, that part between Pathankot and Duneera which drains into the Ravi and Beas.

On first visiting Kangra you get the impression that it is very well wooded district but on closer inspection you will find that 90 per cent. of the trees are very heavily lopped. Every tree so lopped can bear no flowers. No flowers means no fruit and no fruit no seed and consequently when the trees die as they must one day there are no young trees to replace them. The shrub growth is similarly steadily diminishing and the local shepherds are complaining that they have had to abandon some of their old grazing grounds.

I have no hesitation in saying that the time is not far off when the Kangra Valley will be reduced to the same state of desolation as the Hoshiarpur and Ambala Siwaliks

The Gurdaspur District is worse than Kangra

Take the Salt Range or that part which drains into the Jhelum above Rasul. It is almost entirely denuded of all vegetation and most of the soil has been washed away. I may tell you that the only forest produce in some of the forests is stones

In the Jhelum forest division we still have 116,000 acres of so-called forest which is open to goat grazing for at least nine months of the year. As the goats devour every seedling which tries to establish itself under the most trying conditions these 116,000 acres of forest are bound to disappear.

The cause of the destruction which is going on everywhere is the unrestricted grazing of hosts of goats, sheep and cattle As the village grazing grounds become unable to support the animals the burden on the forests become heavier and heavier and they too deteriorate

To give you some idea of the number of animals which this unfortunate country is expected to support:

In Kangra in addition to local animals you have every winter the nomadic Gaddi shepherds pouring down from the high hills of Kangra, Kulu and Chamba Every year they come down to the tune of well over three hundred thousand In Gurdaspur between 50 and 70 thousand animals appear. [illegible]
average 1·4 acres [illegible]
say that it requi[illegible]
condition. How is it possible to expect the vegetation to improve?

There is now a motion before the Legislative Council to abolish the tax on goats, sheep and cattle in Kangra. If this is carried the number are certain to increase and the destruction will be aggravated.

It is easy enough to point out the destruction which is going on and to indicate the remedy but I confess the problem how to reduce the numbers of animals and to regulate the grazing appears quite insoluble but I am convinced that unless action is taken you must expect the floods to increase and the cold weather supplies in canals to diminish.

Mr. Kitchingman —

In south-east France you have a country not unlike the Punjab in its physical configuration You have hills and plains and each year the rains drop on the hills and the water drains down and waters the cultivations in the plains. Professor Huffel, the foremost authority in France on the relation between hill vegetation and floods, goes so far as to say that the very existence of the plains people depends here upon a proper proportion of forest and shrub vegetation covering the catchment areas of the rivers.

In the middle ages the land was owned by large landowners who carefully preserved the forest for hunting; rules were very strict. In 1727 the rules were revised and the punishment for forest offences made very severe; the penalty for felling trees without the King's permission was for a first offence whipping and banishment and for a second offence perpetual galleys. If fire was used to destroy the forest the penalty was either the galleys or even death. These revised rules remained in force until the French Revolution. After the revolution the forests were divided up and declared the property of the villagers, in accordance with the new ideas of democracy introduced by the revolutionary democrats. Wholesale destruction followed, as it was bound to do. Not many years passed [illegible] n the increase...... [illegible] ..Several villagers [illegible]. This is the stage [illegible] ost of the forests to village rights in accordance with our democratic principles we now watch the forests being destroyed—the only ones remaining being those in the *Native States where the forests are the sole-property of the Raj, and in* reserved forests, which are the sole-property of Government. It is a maxim of Forest management that divided-ownership spells the ruin of forests and it may interest to know that the English, who are the most famous destroyers of [illegible] for since the war fore [illegible] to one sole-authority [illegible]

1919 Let us come back to France and see how they solved the difficulty. They started by spending a lot of money on building large bunds in the river beds to stop the force of the floods and save their fields. But they soon learnt that this was insufficient because the floods got worse and worse every year and destroyed the bunds as soon as they were built: and it was not till 1843 that they realised that they must do something to diminish the floods if they were to do any good at all. They surveyed the land and divided it into 1,462 nullahs which were liable to floods. Of these 1,462, 168 nullahs are now finished They are gentle flowing streams, cultivation has come back and prosperity returned. The Forest service estimates that by about 1950, just about 100 years after work started all floods will have ceased. Now how did they do this?

Describing what was done in one particular nullah the speaker said: Let us take the Ubaye river. [illegible] 255,000 acres of which less than 20 per [illegible] nullah is 48 miles and the riv [illegible] only 19,000 have been acquired and closed because to close the whole catchment area would have interfered too much with the grazing rights But, as in all these nullahs where work is going on, the villagers have gradually realised the value of the work and have voluntarily closed their lands and

sold to the Forest Department no less than 14,000 acres of their own village forests. To-day floods have entirely stopped in four distributaries which are now beautifully wooded.

Now all this has not been done without a great deal of trouble politically. It was not till 1860 that a law was passed authorising Government to acquire land which was required for turning into forest. There was at first a terrible outcry against the Forest Department, the hill-people complaining that their rights were being ignored for the benefit of the rich cultivators in the plains In the words of Professor Huffel "The very title of the 1860 law 'Reafforestation of the Mountains'" frightened the people. Was the Forest Department going to seize the whole mountain, cover it entirely with forest, forbid agriculture and pasturage, so as to bring back the solitude and peace of prehistoric times? Violent resistance was made by the hill-people to this law chiefly because much of the cost of the work was debited to the hill-villages where the denudation had taken place as they were considered responsible for the damage. After much political agitation a new law was passed in 1882 and this is in force to-day. It gives Government power to take over the catchment area of nullahs which are in a bad condition but the cost of all work is borne by Government, *i e*, the taxpayer, because everybody in France is considered to be interested So you see that we in the Punjab are not alone in our difficulties—other countries have the same difficulties to face and we can learn a lot from the experience of others

Mr. Prem Nath.

He was afraid he was not fully prepared to speak on the subject before the Congress.

In connection with his duties he had on several occasions to visit the inner valleys of the Himalayas which form the basin of the Sutlej, the Ravi and the Chenab He had noticed that the process of disintegeration of rocks and the denudation of hill sides is rapid This was largely due to the exposure of soil or in other words the absence of vegetation and to the free grazing of sheep and goats in the alpine pasture lands. If we are to save the situation endeavours must be made to protect vegetation in the high hills and so he entirely endorsed the suggestions made by Mr. Holland.

Mr. Mohammad Azim, Extra Assistant Conservator of Forests. expressed his agreement with the views of the authors and urged the necessity of afforestation to check landslips.

Mr. Brayne, I.C.S., Deputy Commissioner, Jhelum, supplied the following written communication :—

He had been going into the question of flooding in the Jhelum District and found that except for the phenomenal flood of 1929, serious flooding has only been caused when heavy local rainfall coincide with a spate from Kashmir. This means that the denudation of the Salt Range is helping materially in the ruin of the riverain tract of the Jhelum District. The people complain that the bed of the river has risen and

this appears to be true. But the cause to my mind is not the Rasul Weir but the silt dropped when the flow of water is checked by the meeting of the Jhelum with the Salt Range torrents.

A large area in the Pind Dadan Khan Tahsil is being rapidly depopulated by increasing salinity The cause of that at first sight appears to be the laying bare of the salt strata of the salt hills by erosion So much for the terrible damage being done by our neglect of the hills

Reafforestation is a far easier problem, however, than many people seem to believe In the Gurgaon hills we have the Maconochie experiments which are 100 per cent. successful, and we have work started in 1925 which inspite of two failures of the rains already shows phenomenal success, and near Jhelum we have the Pabbi experiment. The Gurgaon hills consist of hard quartzite rock, whereas the Salt Range is already in an advanced stage of decomposition, while the cold weather rains are heavier and the frosts are far more severe than in the Gurgaon District so that afforestation in the Salt Range is far easier than in the Gurgaon hills, and if in Gurgaon in five years (including two famine years) such wonderful results can be achieved we need have no anxiety about the success which will attend any efforts made in the Salt Range.

The question has been recently discussed at two well-attended public meetings at Jhel [illegible] both as to the necessity of e [illegible] largely replacing it by [illegible] to the disastrous results of deforestation, and all that is required is a careful organised campaign of public education to enlist the help of the villagers in this important question.

[illegible] for a [illegible] an ir [illegible] conv [illegible] A campaign of propaganda for the substitution of mutton for goats' meat and wool for goats hair would effect a very large reduction in the number of goats kept. These things would cost very little and constitute a very signal advance. The erection of bands in the Salt Ran[illegible] would be extremely popular and could be combined with afforestation in such a way as to make that also popular.

The main ingredient to success in all schemes is the careful and patient education of the villagers to realise the damage done by deforestation and the possibilities and advantages of afforestation.

He wondered if it would be possible, in order to convince the educated public of the urgent necessity of afforestation, for the afforestation of the catchment area to be included in the cost of maintenance of such engineering projects as dams, bridges, banks, etc. Could the forest experts and engineers make a rough calculation as to the run off of a catchment area in its present state and the estimated run off, say 10 years

hence when denudation has continued at the rate it is going on now, and draw up the estimate for the project in the alternative? One estimate assuming that afforestation would be done to and the other assuming continued neglect and allowing a larger outlay to meet the increasing force of the water due to further denudation In this way it is possible that the sanctioning authorities would prefer the annual outlay on afforestation with its many other advantages in preference to the increased initial expenditure on the capital outlay, necessitated by the continued neglect of the catchment area As it was, large sums were being spent on strengthening every work and even then it seems certain that as denudation proceeds the floods are bound to win, whereas if regular sums were spent on afforestation, within a measurable distance of time the remedy will catch up the disease and floods will begin to decrease

Colonel Battye said that apparently engineers were being asked as to what they could do to help In this matter he was of opinion that lawyers could do more to help than engineers.

Regarding Mr. Brayne's suggestion he said that it was by no means original. It was now common practice in the North American Continent to adopt afforestation with a view to postponing the date when the construction of storage dams became a necessity and in some cases to reduce their capacity Afforestation was often a much cheaper method of obtaining storage than the construction of dams.

He also enquired as to what sort of area could be afforested. In

Mr. Glover's reply.

Mr. Glover in reply to remarks by Colonel Battye as to the cost of operations, emphasised the improvement which could be obtained by simple closure and prevention of abuses Nature if given the chance would clothe the ground with fore[illegible]
artificial works. He drew
Punjab with those which h
as so well described by Mr. [illegible]

PAPER No. 136

THE SURVEY AND CONSTRUCTION OF THE KANGRA VALLEY RAILWAY

By

MAJOR R D WAGHORN.

The idea of constructing a railway through the Kangra Valley was by no means new, and various projects had been under consideration since the year 1900.

[illegible] following different routes were carried out [illegible] reports based on these schemes showed [illegible] ie unremunerative.

An aerial ropeway for the transport of goods was also considered and dropped for the same reason Some other justification was therefore necessary.

When the Mandi (Uhl River) Hydro-Electric Project was first mooted, it was [illegible] by road An [illegible] and the maxim [illegible]

It was originally estimated that the first development would require the transportation of some 20,000 tons of material from Pathankot to the Power Station site, out of which some 20 packages at least would weigh from 15 to 20 tons each, while most of the pipes for the penstock would [illegible]

necessary to—

(*a*) Strengthen or rebuild all the bridges.

(*b*) Remetal the entire route once or twice during construction.

(*c*) Purchase tractors and lorries.

(*d*) Make special arrangements for the maintenance of the transmission line.

On the score of cost and the physical impossibility of carrying packages exceeding 22 tons during the second development of the scheme, there was no point in pursuing this investigation further.

Various Tramway schemes were also considered by the Hydro-Electric Branch of the Punjab Government :—

(1) To build a Tramway along the road. An examination of the road and its steep gradients placed this proposal out of court as a commercial proposition.

[illegible]

(3) To build a tramway along the route reconnoitred by the N. W. Railway in 1914. The difficult nature of the country, however, precluded the adoption of this project also

In view of the possibility of the N. W. Railway extending the broad [illegible] Mukerian to Talwara, the Hydro- [illegible] plored the merits of a 2"-6" [illegible] Talwara to Baijnath.

This scheme was turned down in favour of a metre gauge project which would allow of electrification at a future date, and was vigorously advocated by the Chief Engineer of the Hydro-Electric Branch as the most promising solution of the problem.

As a result, detailed investigations regarding the feasibility of a metre gauge tramway following the same alignment, were carried out during 1923- [illegible] of a line betw [illegible] was Rs 98 C [illegible]

The intention was to extend the broad gauge Jullundur-Mukerian line to Talwara on the understanding that this portion would ultimately be paid for out of N W. Railway funds, for which there appeared to be justification, the remainder of the line being constructed through the Agency of the P W. D Hydro-Electric Branch, with funds provided by the Punjab Government A ruling grade of 5 per cent. compensated was selected, and a maximum curvature of 40°, and on the grounds of economy the Beas crossing was to be effected by a submersible bridge.

In 1925 the Punjab Government referred the matter of this construction [illegible] tions it [illegible] ference [illegible] struction and working of the line being undertaken by the N. W. Railway As the traffic prospects of this line were not sufficient to justify this construction being undertaken by the Government of India as a commercial proposition, the Punjab Government agreed to guarantee the line This guarantee was limited to a payment of Rs four lakhs a year for a period of 13 years In agreeing to this proposal the Punjab Government stressed the urgent necessity of communication being established at the earliest possible date in order that there should be no delay in the introduction of the supply of current from their Hydro-Electric scheme.

In April 1925 preliminary investigations were started.

Topography.

Plate I.- [illegible] at Pathankot to the terminus at [illegible] ricts of Gurdaspur and Kangra [illegible] portion of the line lying within the Kangra District.

...ing ... W ... ape

...s reaching a ... direction t... series of open valleys which widen eastwards, to be cut off by the succeeding Sub-Himalayan ridge Finally, to the east of Shanan, the main Dhauladhar range curving to the south-east closes the Kangra Valley, and separates it from the mountainous valleys of Kulu to the east

The numerous torrential streams, fed from the snows of the Dhauladhar range, in general continue in the same southerly and south-westerly direction across these open alluvial valleys in deeply eroded courses. On reaching the south side of the Kangra Valley, they are diverted in a north-westerly or south-easterly direction along the north side of these foot hills Here joining forces under the names of Banganga, Jugal and Neogal rivers, they cut through these lower ridges which bound the Kangra Valley to the south and, linking up with the tributaries which drain the southern slopes of these outer hills, they continue southwards to join the waters of the Beas river.

Taking advantage of these river valleys which traverse the foot hills, the railway runs for the greater part of its course over the open valleys of Jawali, Kangra, Palampur and Ahju to Shanan in Mandi State.

During early May these wide open valleys, covered with ripening wheat crops and hedge rows of sweet scented roses and honey suckle, contrast markedly with the mountainous grandeur of the Dhauladhar range to the north. From a point of view of scenery it would indeed be difficult to surpass the beauty of this Himalayan tract

During May and June 1926 a survey of the area traversed by the railway was carried out by the Geological Survey of India.

Although Geological considerations did not play such an important part in the final location of the line as was the case in the Khyber Railway, the information was in some cases of very considerable importance.

In the section of line between Baijnath Paprola and Ahju it is a question whether sufficient consideration has been given to this aspect of the problem

The alignment as finally fixed runs along the left bank of the Bhir Khud, a nullah with very precipitous side slopes, composed of massive jointed sandstones.

These dip into the river at an angle of some 35°, and a good deal of trouble has been experienced from slips in this section It is possible that it would have been cheaper in the long run to have accepted a somewhat expensive crossing of the Bhir, and carried the alignment up the opposite bank.

Trouble has also been experienced in the Valley of the Banganga and the section between Nagrota and Palampur. Here sandstones alternate with bands of a dark red clay; this clay weathers very rapidly, causing the overlying sandstone to fall away in large masses. In this case, although trouble was anticipated, the position had to be accepted as there was no alternative.

It is well known that the Kangra Valley is subject to intermittent earthquake shocks, and was the centre of a very destructive earthquake in 1905.

F [illegible] quake [illegible] sustair [illegible] comparatively immune.

These facts have, wherever possible, been taken into consideration [illegible]

General Description of the line.

Plate I and II.—The Railway is a single line of 2′-6″ gauge and its length from Pathankot to the Hydro-Electric Stores Yard at Shanan is 103·1 miles. Between Pathankot and Baijnath the maximum gradient is 2·5 per cent. and the maximum curvature 14° (=409 feet radius). Between Baijnath Paprola and Jogindernagar the gradient is 4 per cent. and [illegible] is). Between Jogindernagar and the [illegible] per cent grade has been adopted, this [illegible] a siding, the terminus for passenger [illegible] mpensation for curvature has been [illegible] gree, and all curves transitioned, the [illegible] arthwork in banks [illegible] tunnels and over [illegible] es of 40 feet span [illegible] 22 recommended [illegible] ″ wide and 10′-6″ high.

Survey and Location Work. General.—Plates I and II.

As soon as orders were received survey parties were sent in to the field.

[illegible] were to a [illegible] work was almost complete, it was found that maps to a scale of 4″ to 1

mile were in print and available with the map section of the Forest De-

Those who have had experience of railway construction (or it might almost be said of any form of construction work) where time is a vital factor, will realise that the fixing of the alignment was a matter of primary importance; the acquisition of land, preparation of Cross Sections, designs, and in fact everything being dependant upon it.

The problem was not an easy one. To have adopted the first alignment that suggested itself without investigating other possibilities, might have meant a great deal of unnecessary expenditure, while on the other hand there was the danger of overdoing the investigation of alternative routes, and a consequent loss of valuable time.

A mean had to be struck.

Section Pathankot to Guler.

The location of this portion of the line presented few difficulties. For the first 12 miles the alignment runs parallel and at a short distance to the south of the P. W D. road, the Chakki river being crossed at mile 7 3. Here the first proposal had been to make use of the existing road bridge; this proposition, however, was eventually ruled out, as experience has shown that the combination of a road and railway bridge is a continual source of trouble A separate bridge has been built a short distance downstream, giving us the advantage of protection from the road bridge above.

Section Guler to Kangra.

Immediately after leaving Guler trouble started, the problem being the crossing of the Banganga or Baner River.

Two main alternatives presented themselves, and they were briefly as follows :—

To remain on the right bank and to effect a crossing if possible at a point somewhere near the P W D road bridge. This al

almost impossible bit of country just short of Kangra itself.

The second was to cross the river as soon as possible and to follow [illegible] this portion would prove very costly. Experience has shewn that it is always best to " lump " the heavier work, instead of having to continue desperately contouring the outer features, thus getting away from the objective.

Immediately after leaving Guler and running through extremely [illegible] gorge on to comparatively easy country.

At mile 52 another partial descent, involving further difficult location work, was found necessary in order [illegible] Khad (mile 53), an important trib [illegible] From [illegible] rough a [illegible] lopes of the river.

[illegible] efforts to get round; a second and somewhat longer tunnel had to be accepted Once through the ridge a short fall brings us to Kangra station site at mile 59.

Section Kangra to Palampur.

[illegible] ry lying to the [illegible] line drops to [illegible] very difficult [illegible] of something over 200 feet

From here the valley opens out considerably, and it was found economical to drop down on to the lower slopes in order to reduce the height of the crossings necessary over the numerous nullahs, which have their catchment in the high ground to the south.

[illegible] le 61·8. The [illegible] omerate bluff [illegible] sance it was thought that owing to the danger of slips occuring, the alignment along the cliff would not be feasible, and to avoid this a double crossing of the Banganga had been proposed. On closer investigation it was found that the conglomerate was both compact and well consolidated, and it was considered that the money thus saved justified the risk being taken. Results have entirely justified this decision.

valley
Pass,

For a consideration of the next section three controlling points should be noted, namely, the Nagrota Pass, the Paror ridge and the crossing of the Neogal, the differences in level of the first two being only some 15 feet.

The development up to the Nagrota Pass, although involving fairly heavy work, produced no serious problem as far as location was concerned. Where development is necessary, such as in this case and in the case of Talara, it is always necessary to work out the alignment from the summit downwards taking account of controlling points

expenses and it was decided that the upper line would in the long run prove the most economical. From the Paror ridge to the Neogal is a distance of only 1,600 feet with a difference in level of 107 feet, which
the
but

From the Neogal crossing, the line runs at a maximum grade up to Palampur station at mile 79 3, the question of alignment being purely one of detailed location, and making the best possible use of the ground.

Section Palampur to Baijnath Paprola.

The siting of Palampur station at a distance of 2½ miles from the town has caused a certain amount of criticism, but here again a study of the facts is necessary. The difference in level between Palampur station and the crossing of the Binwan Khud at Baijnath is approximately 600 feet, the distance being about 9 miles ; after making allowances for future

clear.

It i
the rou
and is
or high banks over a
ring round the nullah
ticable, as not only c
a rough estimate of
shorter and straighter alignment to be the better and more economical of the two.

Baijnath Paprola to Shanan.

Baijnath Paprola station is situated in an open level stretch above the banks of the Binwan Khud. The crossing of the Binwan and the approach to it from both sides required a great deal of care in the detailed location work as the ground at our disposal was severely limited by the P. W. D. road to the north and the river itself to the south and west.

[illegible]
a [illegible]
P [illegible]
without any appreciable break.

Location work in the Bhir proved exceptionally arduous as the valley is heavily wooded and the side slopes in places are precipitous.

[illegible]
the capitalised cost of the extra running expenses in the other, the balance proved to be in favour of the lower route with the consequent rise again on approaching Shanan

In extremely difficult country the temptation to introduce sharp [illegible]

[illegible] curvature is very [illegible] have to be r[illegible] of such great importance, is that of comfort to passengers. Those who have travelled on the Kalka-Simla Railway will readily appreciate this.

As regards the question of grade it should be noted that the line rises and falls and that the gradients selected vary according to the nature of the country. The adoption of a steep ruling gradient throughout the greater part of the line is both unnecessary and impracticable and, the saving in capital cost by utilising the heaviest grades possible in isolated short lengths is not justifiable when it reduces train loads and puts up considerably the working expenses. In tackling this problem of grade and curvature it is necessary to have a full knowledge of the facts governing the problem, and to keep them in their true perspective.

Organisation and Plan of Operations.

As details of the organization may prove of assistance in the case of future railway construction of this nature, these have been given in Appendix I.

In order to consider the adequacy or otherwise of the organisation adopted, it will be necessary first to state briefly the various duties for which officers were held responsible.

From October 1925 up till November 1926, the Superintendent of Works' responsibilities were confined to the Kangra Valley Railway; in December 1926, however, re-organisation took place, and the various construction works in progress on the N. W. Railway were organised into circles.

In addition to his duties on the Kangra Valley Railway the Superintendent of Works was, under this re-organisation, made also responsible for the re-construction of the Khyber tunnels, the construction of the Ravi Bridge and the lines connected with it

[illegible]

value of stores which passed through the depôt at Pathankot amounted to something over 80 lacs of rupees, and when other work was at its height, there were some 80 pumps, steam hoists, compressors and other types of machinery in use on the various works.

The other two Executive Engineers each had lengths of 40—45 miles with three Sub Divisional Officers working under them.

Owing to the fact of roads being practically non-existent, the Executive Engineer No. 1 Division had to carry out almost the whole of the inspection of his Division on foot, a complete inspection necessitating his absence from his Headquarters for the best part of a week.

With the exception of the larger girder bridges, the design and separation of all drawings was carried out in the Divisional offices, help being given in the work by type designs issued from the office of the Superintendent of Works.

In December 1926, the accounts, which had up to that date been prepared by the Superintendent of Works, were transferred to Divisions, thereby greatly increasing their work.

In the easier portion of the line, Sub-Divisional Officers had lengths of approximately 20 miles, but these in each case included one of the largest bridges on the line namely, the Chakki and the Gaj.

In the more difficult sections, Sub Divisions were reduced to lengths of eight to nine miles, while in the medium sections the lengths were about 12 miles.

In order to obtain some idea of the responsibilities of Sub Divisional Officers it may be noted that, on an average, yearly payments to contractors alone amounted to some eight lacs of rupees. Measurement work in country such as is met with on the K. V. Railway is extremely arduous, taking up time and labour comparable to that for measuring double the quantity of work in the plains.

Finally, it must be remembered that for the greater part of the time survey, construction, and estimating were being carried out simultaneously.

In Appendix I an alternative organisation has also been suggested; this may possibly be considered as on the generous side, but it is submitted that in a work where speed is of vital importance, economy in the matter of staff is not good policy.

As soon as the preliminaries of survey and land acquisition had been completed sufficiently to allow of construction work to start, a programme was prepared. This aimed at, and was based on the assumption of railhead reaching Shanan by April 1928, the original date given to the Hydro-Electric Department.

it wa

name

tion, and every effort was made to get these three completed to time.

It will also be obvious that delays if they were going to occur would most likely be met in the lower sections of the line, as in the upper sections more time would be available.

It is not proposed to go into details here as to the numerous causes of delay, as many of these will be dealt with subsequently when dealing with the works themselves

Plate III shows the actual linking progress achieved from month to month, and on this, notes have been given which explain the cause of time being lost at various stages. That the programme aimed at origi- saying, and whether it was an question to answer, but the sis should a programme be prepared?

It must be optimistic in order to give the necessary incentive, but at the same time it must also be practicable; delays are bound to occur and reasonable allowance must be made for them; a careful study must be made of the whole situation and the controlling points decided on. The " ideal " its own obj d, are apt of paper " ing in corresponding disorganisation of the work to meet new conditions.

Construction. General.

By May 1926 possession of land was given in the lower portion of the line and work was able to begin; previous to this, sanction had been obtained from zemindars to start work on certain pieces of waste land, but this was only in a few isolated cases.

The Kangra Valley is one of the wettest districts of the Punjab, he end of September, between 70 and 100 Palampur in 1927. ich occurs between

December and February The working season can therefore be taken to extend from the end of September to the end of June, with a break of say a month in the winter, or a total period of eight months out of the 12.

Considering the line as a whole there are examples of almost every type of work likely to be met with on Railway Construction, and it was the variety that proved of such peculiar interest; as a training ground it would be hard to find a better. It is now proposed to deal with the various difficulties met with under their different heads and the methods employed to combat them.

Earthwork.

As already mentioned the quantity of earthwork in cutting and bank amounted to some 5 8 million cub yards and of this the greater part was either in rock, conglomerate, or in a formation consisting of hard compacted boulders.

In the long side-long cuttings of the Banganga, and again on the Nagrota Pass, Paror and Bhir Khad sections, there were always the two alternatives to be faced — that of keeping out from the hillside, necessitating a large number of retaining walls, but a corresponding reduction

Practically all the heavy work was done by imported labour, Gurkhas, Tibetans and Kashmiris appearing in fairly large numbers, but Pathans, of whom Afridis were in the majority, formed the greatest number.

Certain contracto s tried using local labour but in addition to appearing unable to tackle the work their physique proved to be a further disability.

Ingersoll Rand Portable Compressors did excellent work, many of these having already seen life on the Khyber Railway; owing to the

in many cases contractors preferred to supply their own powder, but gelignite was supplied from railway magazines situated at intervals along the line.

Altogether some 7½ miles of tramway track were used on this work, but the use of this had to be confined to through cuttings where long leads were involved or where heavy rock and boulders required handling, elsewhere the long-suffering donkey came in for his share of the work.

Retaining Walls and Breast Walls.

[illegible]

As soon as the preliminaries of survey and land acquisition had been completed sufficiently to allow of construction work to start, a programme was prepared. This aimed at, and was based on the assumption of rail-head reaching Shanan by April 1928, the original date given to the Hydro-Electric Department.

[illegible] it wa [illegible] nam [illegible] tion, and every effort was made to get these three completed to time

[illegible] they were going to occur would [illegible] of the line, as in the upper sections [illegible]

It is not proposed to go into details here as to the numerous causes of delay, as many of these will be dealt with subsequently when dealing with the works themselves

Plate III shows the actual linking progress achieved from month to month, and on this, notes have been given which explain the cause of time being lost at various stages. That the programme aimed at originally was an optimistic one, there is no gainsaying, and whether it was an impossible one to work to is a very difficult question to answer, but the question which does arise is—on what basis should a programme be prepared?

It must be optimistic in order to give the necessary incentive, but at the same time it must also be practicable; delays are bound to occur and reasonable allowance must be made for them; a careful study must be made of the whole situation and the controlling points decided on. The "ideal" programme which allows of no delays is apt to defeat its own object, in that staff, when they see work getting far behind hand, are apt to become demoralised and treat the programme as a "scrap of paper"; also drastic revisions will eventually be found necessary, resulting in corresponding disorganisation of the work to meet new conditions.

Construction. General.

By May 1926 possession of land was given in the lower portion of the line and work was able to begin; previous to this, sanction had been obtained from zemindars to start work on certain pieces of waste land, but this was only in a few isolated cases.

The Kangra Valley is one of the wettest districts of the Punjab, the rains generally lasting from early in July up to the end of September, the rainfall in this period amounting to something between 70 and 100 inches, the latter figure being actually recorded at Palampur in 1927. There is also a considerable winter rainfall which occurs between

December and February The working season can therefore be taken to extend from the end of September to the end of June, with a break of say a month in the winter, or a total period of eight months out of the 12.

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Retaining Walls and Breast Walls.

of breast walling. Plate IV, Figs. 2 and 3 shows two types of section used, tl [illegible] where the wall was retainir [illegible] ype shewn in Fig. 2 being [illegible] advisable to reduce the amount of cutting-back to a minimum, nearly all the batter being kept on the face. It must not be supposed that these types were strictly adhered to, as considerable modifications were made, depending on the actual conditions met with For instance, both in the Banganga gorge and on other parts of the line, there are places where massive sandstone outcrops overlie thick bands of a reddish clay; once exposed the latter weather very rapidly. In such places it was found sufficient if little more than a skin of masonry were used, underpinning the rock above and preventing any further weathering of the clay beneath.

At Paror ridge, (where it will be remembered that a heavy cutting was found necessary in order to get down to the Neogal Crossing), a great deal of trouble has been experienced.

[illegible] seen that the cutting takes [illegible] latter running at a high [illegible]

Although it was thought that a retaining wall would eventually be required, the cutting showed little signs of movement during the first year. In January of this year, however, cracks began to appear, first on [illegible] to the centre line of the railway.

A retaining wall was at once started and was partly completed. Soon after [illegible] plete [illegible] the b [illegible] carefi [illegible] amounted to about an inch to an inch and a half in 24 hours. It was evident that the only remedy for stopping this movement, was a cut and cover, provided it could be got in in time. Every effort was being made [illegible] dropped three to four feet, the wall being pushed [illegible] squeezed the track up some two to two and a half feet. An Inspection of the site, immediately afterwards, showed that the whole mass of disintegrated sandstone forming the upper portion of the hill was sliding over the thick band of red clay beneath, and in places where this was exposed it showed a clean polished surface.

By clearing the greater part of the overload away, and taking the foundations down to some 10 feet below the level of railway formation, all further movement was stopped. Before filling in again behind the

retaining wall, care was taken to stop back the clay, to prevent it from once more becoming a sliding surface.

Had the line at the time not been opened to traffic, it would have [illegible]

acted as a buttress It is in cases such as these that formulae and theories are rather apt to go by the board

Tunnels.

Neither of the tunnels provided any serious problem Both were luckily in good ground, Dhu [illegible]

In order to save expense in the supports for the arch centering for [illegible]

feet in length, two sets of centres being in use at either end, one supporting the finished arch and the other ready to be carried forward for starting work on a new length.

Behind this again another party was started on the opening out of the lower half of the tunnel, and finally side walls were put in.

It was found that the work of arching and side walling could more than keep pace with the excavation and that it was the latter that really governed the rate of progress.

[illegible] cellent work. [illegible] Daulatpur in [illegible] the case of [illegible] fig. I shows type of section adopted.

Bridging.

With an annual rainfall of some 120 inches it will be realised that Bridge work proved to be an exceptionally heavy item, see Appendix II, and it was here that most of the difficulties were met with

It will be convenient to divide the work under three headings: foundations, superstructure, and girder erection.

Foundations.—Broadly speaking the types of subsoil met with may be divided into three groups: Coarse sand and gravel with occasional boulders, compacted boulders, and rock; the latter presented no problems, and may therefore be neglected.

Examples of the first group were met with in both the Chakki and Gaj.

Before work began on the Chakki, every effort was made to get some details of the construction of the P. W. D. road bridge, but none were forthcoming. To be forewarned is to be forearmed, and here was a case where a completion report, or even the scantiest details would have been of extraordinary value.

The bridge, as originally designed, consisted of 39—40 feet spans, the shortness of the spans being accounted for by the fact that a large number of 40' girders were available from broad gauge lines at a very low cost.

It was hoped at first that it would be possible to sink open foundations, but after trial pits had been made there was found to be a very strong flow of subsoil water, and it was evident that wells would be necessary. These were made of concrete cast *in situ* and proved very satisfactory. As work progressed the problem of dealing with the water became very [illegible] wells by substituting larger spans. This relieved matters considerably, but even so, when work was at its height no less than 40 pumps varying from 3" up to 8" diameter were in use All sinking was done by hand, and work was carried on day and night. Considerable trouble was caused by boulders being met with at the lower depths; these got wedged [illegible] using small charges, [illegible] curred. Foundations were sunk to an average depth of some 20 to 25 feet and in nearly all cases the clay strata underlying the sand was reached

Difficulties at the Gaj proved to be very similar to those met with at the Chakki

Wells again were sunk, the well curbs being made up of steel sections of th[illegible] and [illegible] carried on day and night. Here again the great difficulty was boulders getting under the well curbs, all efforts with the grab failing to move them. As in the case of the Chakki, small charges placed under the boulders were found to be the only effective means of breaking them up, and as these had to be placed under water, the services of two divers had to be requisitioned, the firing being done electrically.

As pumps became available from the Chakki it was possible to pump the wells dry and the laying of the charges and the removal of the boulders became a comparatively simple matter. Wells were sunk to an average depth of from 20 to 25 feet.

To take the second group, namely those in compacted boulders: the nullah beds being usually very steep and almost invariably wet, and the boulders anything upto 6 or 8 feet in diameter, open founds were adopted, and there was nothing for it but to clear away this enormous

mass of rock. It was soon realised that founding in this sort of ground was going to prove extremely expensive, and it was also evident that water was again going to be a trouble; wherever possible spans were increased so as to avoid as far as possible having to found in the bed of the nullah itself.

exceptionally heavy flood in 1927, so the figure may be considered adequate.

Superstructure.

Plate IV, figs 4 and 5 shows two type designs adopted for arched bridges and culverts. There were a certain number of failures with the type in figure 4 using the straight return. These occurred where the arch

rally took place by the parapet wall itself collapsing, but in many cases the first few feet of arching was also pushed out Wherever splay wing walls were adopted no signs of movement took place even under the worst conditions, the wing walls not only acting as a buttress to the arch but also considerably reducing the unsupported length of the parapet walls; the conclusions to be drawn from the above are fairly obvious.

Wherever the slope of the nullah exceeded one in eight it was found that pucca flooring throughout was necessary, but in other cases hand packed stone, with curtain walls as shown in the diagram, proved successful.

In the case of piers of girder bridges, a design using either mass
was adopted. It may
om earthquakes, rein-
r flexibility. It will,

Before designs were started catchment areas were taken out for all
slope, and vegetation were
the method described
was calculated. The
results obtained have proved satisfactory.

* Minutes of Proceedings Inst. C.E., Vol. ccxvii. p. 267.

Girder Erection.

and adequate supply of finished work.

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derrick was found necessary in the final stages. In the case of spans 60 feet and over, these were with the exception of the Banganga and the Reond Arch, taken to site either by road or rail, erected in the nullah bed, and lifted into position by steel lattice derricks; the latter were built up in sections, extremely light, and capable of lifting upto a height of 100 feet

to have them proved an ex- the advantage gained in foundation work, by their use.

The erection of both the Banganga and the Reond steel arch deserve special mention.

The temporary piers, on which the staging was to be erected, were completed on June 9th, 1927, and the erection of the staging and service girders was begun immediately. During the ensuing three weeks, work was carried on day and night in an effort to complete erection from the river bed before any floods occurred. Unfortunately the monsoons broke early, and on the morning of 6th July heavy rain fell, and did such serious damage to s for the steel work, that all further work

On 25th July the river rose 20 feet and scoured and tilted the tempor- -ful inspection it was as much material as amage. When about 50 per cent. of the floor system of the 250 feet span had been salvaged, the river rose 40 feet and carried everything before it. This was on August 1st, 1927.

Finally, the work of rebuilding was started in October 1927 and completed on January 12th, 1928.

The Reond steel arch, of a span of 180 feet with two approach spans each of 40 feet, was unique, in that it was the first of its type to be either erected or manufactured in the country.

The bridge was designed by the Consulting Engineers Messrs. Rendel Palmer and Tritton and fabricated by Messrs. Braithwaite and Co., Bombay.

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overhead ropeway supported on steel towers, constructed so as not to interfere with the running of trains when the bridge was completed. Although as previously stated, the construction of a bridge of this type had never previously been attempted in India, the work was carried out so accurately, that when the two halves of the arch came to be joined up at the centre there was an error of less than 1-16 inch.

In order to save time the whole of the steel work of the arch, weighing in all some 300 tons, was taken to the site by road and was erected before railhead reached the bridge. Plates V, VI and VII show the por [illegible]
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In order to emphasize the importance given to the time factor, a reference may be made to the section between Palampur and Baijnath Paprola. In this length of some 9 miles there are some 23 nullah crossings; it was at first proposed to design all these as girder bridges but calculations [illegible]

of some two months was thus saved.

Had the completion of the work not been of such extreme urgency, it is a question whether for piers of girder bridges, some form of standard- [illegible]
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Materials and Transport.

During the period of survey, very careful notes were taken of what building materials were likely to be available from local resources.

Girder Erection.

The total weight of steelwork involved was approximately 5633 tons,
only of the 180 feet

working out detailed
intenance of a regular
and adequate supply of finished work.

For the erection of spans upto and including 40 feet a portable derrick mounted on a truck was used; this was capable of lifting and swinging into position a complete girder. In the case of 60 feet spans a steel lattice derrick was found necessary in the final stages. In the case of spans 60 feet and over, these were with the exception of the Banganga and the Reond Arch, taken to site either by road or rail, erected in the nullah bed, and lifted into position by steel lattice derricks; the latter were built up in sections, extremely light, and capable of lifting upto a height of 100 feet.

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gained in foundation work, by their use.

The erection of both the Banganga and the Reond steel arch deserve special mention.

The Banganga consists of 1 span of 250 feet and 4 spans of 60 feet. For the erection of the 250 feet span, two service girders of 120 feet each, supported on temporary staging were utilized.

The temporary piers, on which the staging was to be erected, were completed on June 9th, 1927, and the erection of the staging and service girders was begun immediately. During the ensuing three weeks, work was carried on day and night in an effort to complete erection from the river bed before any floods occurred. Unfortunately the monsoons broke early, and on the morning of 6th July heavy rain fell, and did such serious damage to the cuttings and embankments, between the dumps for the steel work, which were seven miles in rear, and the bridge site, that all further work was for the time being impossible.

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from the two abutments, the steel work being handled by means of an overhead ropeway supported on steel towers, constructed so as not to interfere with the running of trains when the bridge was completed. Although as previously stated, the construction of a bridge of this type had never previously been attempted in India, the work was carried out so accurately, that when the two halves of the arch came to be joined up at the centre there was an error of less than 1-16 inch.

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railway construction in India.

In order to emphasize the importance given to the time factor, a reference may be made to the section between Palampur and Baijnath Paprola. In this length of some 9 miles there are some 23 nullah crossings; it was at first proposed to design all these as girder bridges but calculations showed that even under the most favourable conditions the time required for girder erection alone was three months. As a result all the crossings except the five major ones, were converted to arched bridges and a period of some two months was thus saved.

Materials and Transport.

During the period of survey, very careful notes were of what building materials were likely to be available from local r

Unlike a construction in the plains where a temporary line can be quickly run through and materials brought up by train, the conditions imposed in a hill railway necessitate the work being completed before railhead can advance, and diversions or works of a temporary nature are out of the question. These facts, combined with, in many cases, the complete lack of roads of any sort, and the enormous leads involved, made it of the utmost importance to utilize such materials as were available at site.

That this principle was actually adhered to is evidenced by the variety of materials used. Brickwork cement concrete, sandstone and a rather poor type of granite boulder were all utilised in the various sections in which they were to be found.

There was considerable doubt at first over the advisability of using the granite boulder stone. *It was found to contain a fairly large percentage of mica*, and when broken up into small pieces and exposed to moisture, it tended to crumble. Samples were sent for test and as far as compression figures were concerned the results were entirely favourable. As for its weathering properties, a study of the stone in its natural state showed that it developed a hard black skin, much harder than the inner portion of the stone itself. The decision arrived at was to allow of its use in large blocks, but to rule it out entirely an aggregate for concrete work.

Good sand was on the whole fairly plentiful, although in certain sections it had to be led for considerable distances.

One item of interest was the using of a cement and lime mortar. Although the idea cannot be claimed to be an original one, as it is advocated in many modern text books, the use of cement and lime together may be new to some, and may also lead to a certain amount of criticism.

Good lime was to be obtained in large quantities in various parts of [illegible] result, and the economy effected was considerable.

It should be added that its use was limited to bulk work. In the more important works, and in places where work had to be carried out in damp or wet localities cement mortar was used, the proportions following normal engineering practice. The actual proportions used for the lime cement mortar were 3 c.ft. cement 10 c.ft. lime 27 c ft. sand.

The problems of transport is often one which is apt to be overlooked or underestimated, but nevertheless it is of vital importance in the successful and rapid completion of a work of this magnitude, and especially so where time was of such value.

From a study of the key plan Plate I it will be seen that although certain sections of the line were well served by roads fit for wheeled transport there were many portions of the alignment, where not only did no

such roads exist, but it was impossible owing to the nature of the country to build them except at enormous expenditure which could in no way be justified.

The two District Board roads, namely from Nurpur to Jawanwala Shahr and from Kangra to Jawalamukhi Road were only fit for wheeled traffic during dry weather, both being unmetalled, and even then a great deal of maintenance work was necessary to keep them open.

From Jawanwala Shahr, where the District Board road leaves the alignment it was found feasible to make a fair weather service road along [illegible] done.

Lorries, bullock carts, donkeys and camels were all utilized in their particular spheres of usefulness. The principle adopted was to cart materials from Pathankot to the main dumps situated in the various sub-divisions, and from these they were led by the contractors actually doing the work

APPENDIX I.

Organisation.

		Remarks.
Head Quarters.	Superintendent of Works	.. From October 1925 to December 1926 responsible for K. V. Railway only. From December 1926 until completion, Superintendent of Works becomes Superintendent of Works, Northern Circle, including rebuilding Khyber Tunnels, Ravi Bridge and parent lines.
	Personal Assistant to Superintendent of Works.	To assist Superintendent of Works owing to extra work involved on formation of Northern Circle. February 1927 to completion.
No. 3 Division.	Executive Engineer	.. Responsible for receipt and issue of all stores and running of all plant and also incharge of section from Mile 0—20.
	One Assistant Executive Engineer.	Mile 0—20.
No. 1 Division.	Executive Engineer	.. Incharge of Section. Mile 20—60.
	Three Assistant Executive Engineers.	Mile 20—41. Mile 41—51. Mile 51—60.
No 2 Division.	Executive Engineer	.. Incharge of Section. Mile 60—103.
	Three Assistant Executive Engineers	Mile 60—74. Mile 74—89. Mile 89—103.

Actually only 5 Assistant Executive Engineers were allowed in Divisions I and II. One of the Assistant Executive Engineers therefore

The whole organisation was under the control of the Chief Engineer, Surveys and Constructions, Lahore.

Suggested Alternative Organisation.

Head Quarters.	Chief Engineer	.. Responsible for the construction of the Kangra Valley Railway only and with full powers
	P. A. to Chief Engineer.	
Stores & Mechanical Division.	Executive Engineer	.. Incharge of receipt and issue of all stores and running and maintenance of all plant.
No. 1 Division.	Executive Engineer	.. Mile 0—40.
	Two Assistant Executive Engineers.	Mile 0—20. Mile 20—40.
No. 2. Division.	Executive Engineer	.. Mile 40—Mile 64.
	Three Assistant Executive Engineers.	Mile 40—Mile 48. Mile 48—Mile 56. Mile 56—Mile 64.
No. 3 Division.	Executive Engineer	.. Mile 64—Mile 103.
	Three Assistant Executive Engineers.	Mile 64—Mile 76. Mile 76—Mile 89. Mile 89—Mile 103.

APPENDIX II.

List of Bridges.

Mileage.	Name	Spans. No.	Spans. Length.	Girder Bridges Skew or Square.	Straight or Curve.
6 66	Baghar ..	3	30′	Square	Straight.
7·30	Chakki ..	17	40′	do.	do.
"		2	80′	do.	do.
"		6	130′	do	do.
12·64	Carelli I ..	7	30′	do	do.
16 03	Carelli II .	4	40′	do	do.
26 10	Bhul ..	4	40′	do.	do.
35·18	Gajh ..	10	100′	do	do.
39·74	Minnu ..	5	40′	do	do.
43·48	Sukhad I ..	5	40′	do.	do.
45·95		2	40′	do.	do.
		1	60′	do.	do.
46·16		4	40′	do.	5 Transition Curve.
46·36		4	40′	do.	14 Transition Curve.
46·70		5	40′	30 R Skew	14 Transition Curv.
47·85		1	80′	Square	Transition Curve.
47·96	Banganga ..	4	60′	do	11 & 14 Transition Curve.
		1	250′		
48·40		3	40′	do.	6 Transiton Curve.
50·60	Nagni ..	3	40′	do.	Straight.
53 02	Bathu ..	7	40′	do.	do.
		3	60′	do.	14 Curve.
56·14	Daulatpur III ..	3	40′	do.	14 Transition Curve.
58 67	Jamni ..	3	40′	1—40′ Span 30 R. Skew.	14 Curve.
		1	60′		

Mileage.	Name	Spans		Girder Bridges Skew or Square	Straight or Curve.
		No	Length		
59 23	Reond ..	2 1	40′ 180′	Square	Straight,
59 89	Sukhad II ..	4	40′	do	do.
61 79	Jugal I ..	3 1	40′ 100′	do.	14 Transition Curve.
74 58	Neogal ..	5 1	40′ 100′	do.	Straight.
77·99	Soon II ..	3	40′	do.	do.
79 97	Moul	4 1	40′ 60′	do.	14 Curve.
82 24	Dharam Dai .	3	60′	do.	Straight.
84 57	Awa ..	6	40′	do	do.
86 39	Bithi	5	40′	do	do.
86 93	Poon .	3 1	40′ 100′	do.	14 Curve.
88 50	Binwan ..	4 1	40′ 100′	do.	14 Curve.
92·10	Bhir .	1	100′	do.	Straight.
97 90	Bachgar ..	2	40′	do.	do.
101 50	Googli	2	40′	do	24 Curve,

In addition to the above there are :—

		No. Span.	Length.
9 Girder bridges of	..	1	40'
1 do. do.	..	3	30'
4 do. do.	..	2	30'
6 do do.	..	1	30'
4 Girder bridges of	..	3	20'
2 do. do.	..	2	20'
8 do. do.	..	1	20'
2 do do.	..	2	10'
26 do. do.	..	1	10'
6 Arches of	..	1	20'
9 do.	..	1	15'
18 do.	..	1	12'
1 do.	..	1	12'
		and	
		1	6'
10 Arches of	..	1	10'
2 do.	..	1	9'
14 do.	..	1	8'
6 Culverts of	..	2	6'
38 do.	..	2	6'
21 do.	..	1	4'
2 do.	..	1	3'
1 do.	..	1	2'
3 Barrels of	..	1	3'

404 Rail openings of 2' & 3' Spans.
57 Syphons of 2' & 3' diam.
256 Armco pipes of 2' & 3' diam.
44 Armco flumes of 2' & 3' diam.
3 Over bridges

APPENDIX III.

Progress of Girder Erection of Chakki Bridge.

25-4-1927	.. Arrival of first consignment of steel work at site.
20-5-1927	.. 1st span 133 ft. erected on piers.
26-5-1927	. 1st span 88 ft. " "
31-5-1927	.. 2nd span 133 ft. " "
3-6-1927	.. 3rd span 133 ft. " "
6-6-1927	.. 4th span 133 ft. " "
11/12-6-1927	.. 5th span 133 ft. " "
15-6-1927	.. 6th span 133 ft. " "
18-6-1927	.. 2nd span 88 ft. " "
22-6-1927	.. 1st and 2nd spans 44 ft. "
23-6-1927	.. 3rd and 4th spans 44 ft. "
24-6-1927	.. 5th span 44 ft. "
25th to 30th June 1927	.. Work held up owing to floods in river.
1-7-1927	.. 6th span 44′ erected on piers.
2-7-1927	.. 7th span 44′ erected on piers.
3-7-1927	.. 8th span 44′ erected on piers.
4th to 23rd July 1927	.. Work held up owing to damage to embankments by monsoons.
24-7-1927	.. 9th and 10th spans 44 ft. erected on piers.
25-7-1927	.. 11th and 12th spans 44 ft. erected on piers.
26-7-1927	.. 13th, 14th and 15th spans 44 ft. erected on piers.
28-7-1927	.. 16th span 44 ft. erected on piers.
29-7-1927	.. 17th and last span 44 ft. erected on piers.

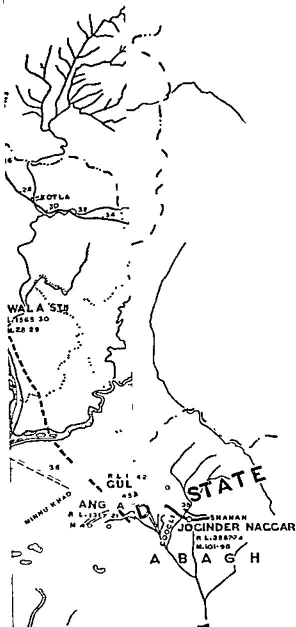
Progress of Girder Erection on Gaj Bridge.

16-6-1927	.. 1st Girder erected on piers.	
17-6-1927	.. 2nd	do.
19-6-1927	.. 3rd	do.
20-6-1928	.. 4th	do.
21-6-1927	.. 5th	do.
22-6-1927	.. 6th	do.
23-6-1927	.. 7th	do.
24-6-1927	.. 8th	do.
25-6-1927	.. 9th	do.
26-6-1927	.. 10th	do.
27-6-1927	.. 11th	do.
28-6-1927	.. 12th	do.
30-6-1927	.. 13th & 14th	do.
2-7-1927	.. 15th & 16th	do.
3-7-1927	.. 17th & 18th	do.

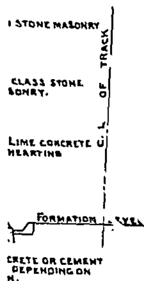
On 4-7-1927 a flood came down the Gaj and submerged and damaged the Service Track.

On 5-7-1927 although the track was still partly submerged the 19th and 20th girders were taken to site and erected.

Before the girders could be lifted into the piers they had to be carried fully assembled, on trollies over a service track for a distance of ¼ mile. The first serious flood occurred on the morning of the 6th, and completely washed out the 2'-6" gauge diversion and B. G. Service Track.

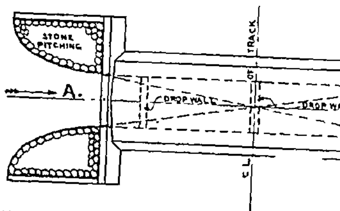

KOTLA
WAL A STN
GUL
ANG A
MINNU KHAD
STATE
SHANAN
JOGINDER NAGGAR
A B A G H

PE OF BREAST WALL.
FIG.2

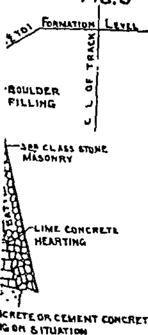


TYPE OF ARCH.
FIG.4

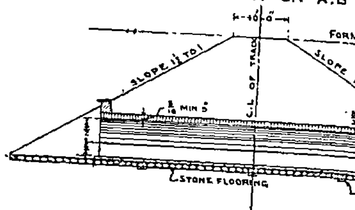
PLAN.



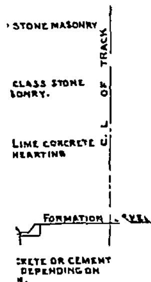
PE OF RETAINING WALL.
FIG.3



SECTION ON A.B

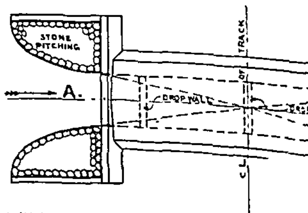


⁼E OF BREAST WALL.
FIG.2

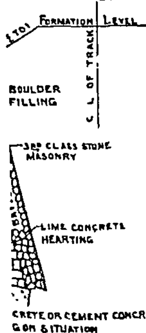


TYPE OF ARCH.
FIG.4

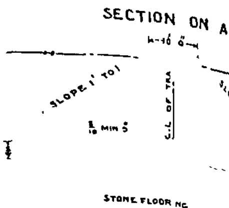
PLAN.

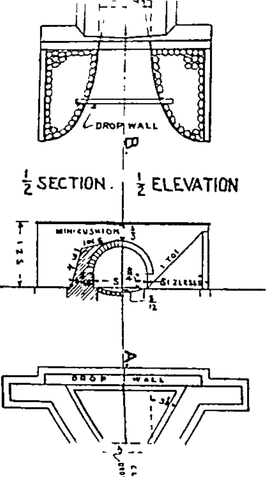


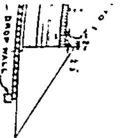
PE OF RETAINING WALL.
FIG.3



SECTION ON A.

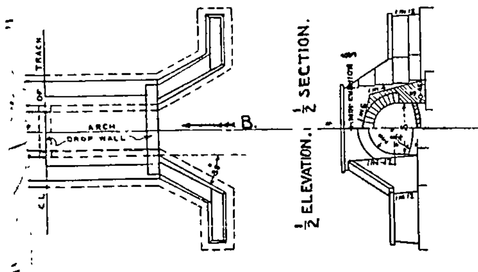



DROP WALL
B
½ SECTION. ½ ELEVATION
MINI-CUSHION
1 TO 1
A
DROP WALL

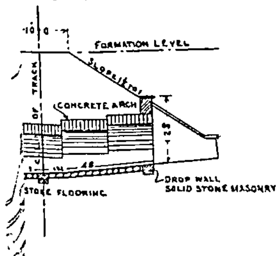

TION LEVEL
DROP WALL

OF ARCH.
FIG. 5

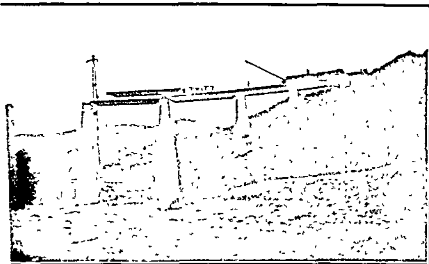
PLAN.



ON ON A.B.

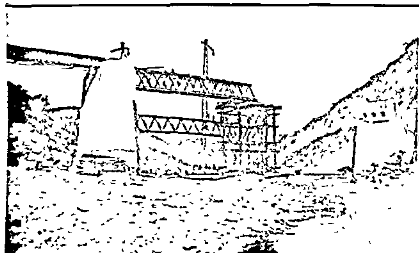


BATHU BRIDGE Plate No. V



Portable Derrick being brought into position to assist in the final stages of the launching of 60 ft. Girder

BANGANGA BRIDGE. Plate No. VI.



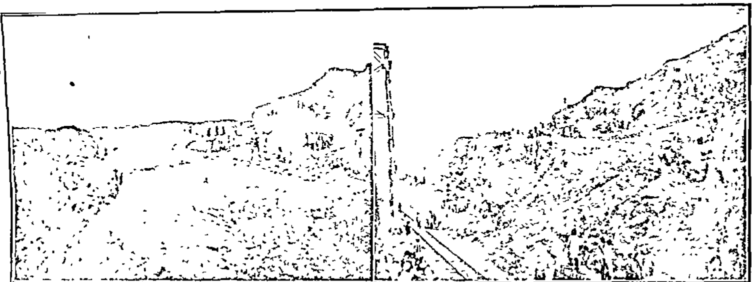
Erection of the Service Girders.

BATHU BRIDGE   Plate No. VII.

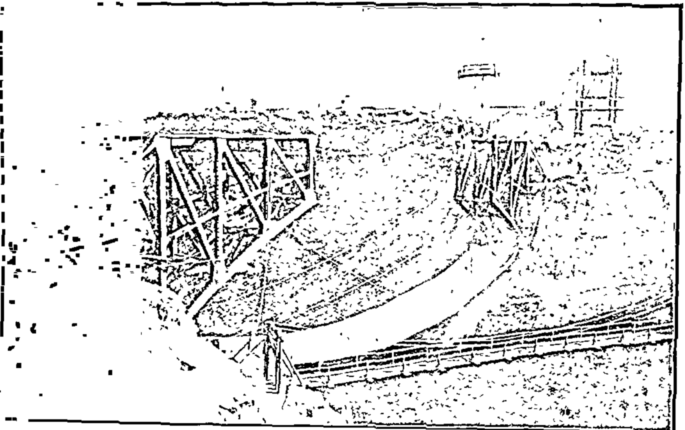


130 ft. Derrick for launching 60 ft Girders.

PAROR RIDGE. Plate No VIII



Cutting showing both Railway and P. W. D road





Erection completed.

DISCUSSION

Major Waghorn, in introducing the paper gave a brief summary of its contents The paper he stated may be divided into three parts.

The first part ... items ... seconc ... and Construction and the methods adopted to overcome these; the third deals briefly with a few interesting problems met with under the heading "Materials and Transport."

The paper commences with a history of the various projects which have been under consideration since 1900 and which have led up to the present construction and explains how the necessity for railway connection with the headworks of the Punjab Hydro-Electric Project was one of the main factors which influenced the undertaking of the project

This is followed by a brief description of the topography of the country and a short general description of the line, reference is made to the extreme instability of the country in general and its liability to earthquakes, both factors which were to influence the alignment and design of works.

... The ... o have ... igating other possibilities might have meant a great deal of unnecessary expenditure, while on the other hand there was the danger of overdoing the investigation of alternative routes and a consequent loss of valuable time. The problem was not an easy one and a mean had to be struck.

The portion of the paper dealing with the construction of the various works is dealt with under separate heads, paragraphs being devoted to earthwork, walling, tunnels and bridging. Of these four there is nothing of outstanding interest in the first three, and although many minor problems had to be tackled, the methods adopted followed normal practice. Bridging proved by far the greatest problem The Kangra Valley is one of the wettest districts in the Punjab and bridgework proved to be an exceptionally heavy item.

Foundations proved extremely troublesome, the majority of these were either in sand mixed with boulders or in compacted boulders up to 8 feet in diameter, most of the nullah beds were wet and in almost every case there was a very strong flow of subsoil water necessitating the maintenance of a very large amount of pumping machinery. These difficulties were to a ... these proved ... up by road ar ...

The total weight of steelwork involved was approximately 5,633 tons practically all of which, with the exception of the Reond Steel Arch, and a few minor spans, was designed and fabricated by the Bridge Department of the North Western Railway in the Jhelum Workshop.

The Reond Steel Arch is unique in being the first steel arch of its kind to be either erected or constructed in this country. In point of view of both speed a[illegible] erection carried out by the Bridge [illegible] one of the greatest achievements i[illegible] in India.

Emphasis is repeatedly laid on the influence which time played in the solving of the many problems met with; this was always the first consideration, involving in many cases methods which otherwise would have been ruled out on the score of cost.

The paper concludes with a brief note on materials and transport. The transport problems proved much more formidable than at first anticipated. Although certain sections of the line were well served by roads fit for wheeled transport, there were many sections where no such roads existed and pack transport had to be resorted to.

Major Waghorn apologised for the lack of figures. This he stated was due to the fact that in December 1928 a fire occurred at Palampur in which the records of two out of three divisions were completely destroyed.

Questions and Replies.

Colonel Battye, stated that there were a few points to which he wished to draw attention. He said that Major Waghorn's paper was particularly interesting to him because it dealt with the problem of trying to locate a surface line at the cheapest possible cost over rough country; he thought the Congress would agree that this was one of the most fascinating problems that an engineer could ever be faced with

The principle the Hydro-Electric Department adopted in locating their tramway was to endeavour to work to the steepest grade they could get, combined with curves up to 40 degree and to stick at all costs to the water shed.

The N.-W. Railway took over the construction of the line and their estimates for traffic were much higher The N.-W. Railway adopted 2·5 per cent. grades and 14 degree curves up to Baijnath and beyond that 4 [illegible]

ar [illegible]

C [illegible]

ceded that the reducing of the curvature to 14 degree on the section up to Baijnath and thence to 30 degrees was sound; it would reduce working expenses and wear and tear on rails and there would be none of the discomfort which is experienced on the Kalka-Simla line.

There, however, was no question of discomfort in going for a 5 per cent. grade.

When the original survey was being carried out by the Hydro-Electric Department it was intended that the line would be eventually electrified at some later date and he maintained that had the steeper gradient been adopted, money would have been available for the cost of plant and

rolling stock required to convert from steam to electric traction when the time came.

He was very interested in the alignment up the Bhir Khud near Ghatta.

The original location adopted by the Hydro-Electric Department crossed right at the bottom of the Nullah and got on to the other side of the hill and he was glad to say that his own judgment of geology had proved to be right. He also wanted to ask whether the reorganization resulting in the Superintendent of Works being made responsible for the works in the Khyber, the construction of new lines at Narowal and a bridge over the Ravi as well as the Kangra Valley Railway, was due to financial stringency or possibly to direct orders from the Railway Board.

He was under the impression that these changes must have made things very difficult for the Engineer responsible and probably cost more than the financial people hoped to save.

[illegible]

money

He felt that it was time that engineers in the Province got together and made a firm stand regarding the extent to which they as Engineers were being converted into Accountants.

He stated that his Engineers on the Punjab Hydro-Electric Project who were all first class men, keen and enthusiastic, were unable to function as Engineers for at least half their time, as it was taken up in performing non-productive and non-technical functions which had been thrust upon them He would also like to know whether it would not have been better to have centralised design work in the Superintendent of Works office instead of its being done in the Divisional offices. He said that he had tried to relieve Executive Engineers of the fundamental design work leaving them free to concentrate on the practical work of construction.

He wished to ask Major Waghorn whether the prices for tunnels at Rs 545 and 485 per foot run, included overhead establishment cost of plant, fuel, etc., used for plant and to what extent interest during construction was included, or if it was merely a net figure

He was very interested to find out how the depth was fixed for foundations; this was a point over which he had had very long discussions and he would like to ask how Major Waghorn arrived at the figure of 12 feet.

He endorsed everything that the author said about girder erection.

He also wished to endorse what the author had said about the granite boulders; they also found that they were quite suitable for stone masonry if carefully selected and used in large enough block; strict orders, however, were issued against its being used as aggregate for concrete work.

In regard to the use of cement and lime mortar mentioned by the author, they had also used it but for a rather different reason and in different proportions. A proportion of ½ lime was added to 1 of cement and they found that by adding this lime they were enabled to work the mortar with a much drier mixture.

Colonel Walton heartily congratulated the author for writing such a valuable paper on the work carried out on the Kangra Valley Railway.

He wished to emphasise one
He did not know whether the
"Economic Theory of Railway

The important point in the location of hill railways was to see that they concentrated the heavy work

Not only was it a good thing to concentrate heavy work in comparatively short sections but it was also sound to concentrate their heavy

always be remembered when faced with a hill railway location.

In regard to the question of grades referred to by Col. Battye he said there was something to be said on the side of capital cost for heavier grades. It was seen, however, that electric power would not be available for three or four years after the line was first opened and that even then it would probably be difficult to justify electric as against steam traction, taking into account the extra capital required for conversion. That was one of the reasons why they adopted the comparatively easy gradients; the other factor being that they wanted to have speed and a steep gradient was a restricting factor because it not only restricts speed up hill but also down, as one has to be careful on account of brakage. Speed he thought was an important factor these days on account of motor competition.

In regard to the Bhir Khud referred to by Col Battye; he agreed with him that the alignment from the geological point of view was unsound. The alternative alignment suggested by Col. Battye was not only thought of, but a trial line was run, it was found, however, that this necessitated a very expensive and lofty crossing of the Bhir Khud and it is very doubtful which of the two alignments would have been cheaper in the long run.

Referring to the heavy work that was put on to the Superintendent of Works, he agreed with Col. Battye and he thought that Mr. E. B N. Taylor, Superintendent of Works, was to be heartily congratulated for the extraordinary way in which he had carried through the work. He wished to mention one or two points in connection with the foundations of the Gaj and Chakki; he thought that there was a very natural tendency for engineers to get their foundations down to such a depth that there would be no possibility of failure due to floods On the other hand there was the financial side of the question to consider and the tendency appeared very often to err on the side of safety; it really seemed to him very largely

to come to a matter of judgment based on experience as to what depth foundations should be taken

It was extremely difficult in cases of rivers like the Chakki and Gaj.

In the case of the Chakki efforts were made to get drawings of the P. W. D. road bridge but these were unfortunately unsuccessful and he thought that in this case foundations were taken down rather deeper than necessary

In the Gaj, however, time was short and matters got to a stage where further sinking was becoming very difficult; this was likely to lead to extra cost owing to another season being required, and he took the responsibility on himself (and then the Chief Engineer agreed) in stopping the wells where they were He was glad to say that so far the bridge showed no signs of failure, but he admitted that it might take many years for his decision to be justified.

Mr. Brij Mohan Lal said that the reconnaissance, survey and construction of a hill railway over 103 miles long in the Kangra District, having 1,000 openings inclu [illegible] in a period of three years and a [illegible] the construction branch of the [illegible] oud of, and on which the officers responsible for the work deserve to be congratulated

The speaker having spent some years in charge of the roads in Kangra District, wished to be allowed to make a few observations on the paper *mainly on the points where the railway as well as road interests were* concerned.

Carriage of the very heavy plant and machinery required for the Uhl Hydro-electric project was not possible along the Kangra Valley Road, nearly all the bridges on this road were built between the years 1865 and 1900, when such heavy traffic could not be foreseen. The gradients on this road are as steep as 1 in 17, and the width is narrow. The road was stressed to its limit during the years 1926 and 1927 when all the [illegible]

The author has discussed on pages 83 and 84 the different alternatives, but has not given any reasons for building the line from Pathankot in preference to Mukerian One distinct advantage in building the line from Mukerian would have been the shorter distance from Mukerian to Jogindarnagar.

[illegible]

In regard to the use of cement and lime mortar mentioned by the author, they had also used it but for a rather different reason and in different proportions A proportion of ½ lime was added to 1 of cement and they found that by adding this lime they were enabled to work the mortar with a much drier mixture.

Colonel Walton heartily congratulated the author for writing such a valuable paper on the work carried out on the Kangra Valley Railway.

He wished to emphasise one [illegible]
He did not know whether the [illegible]
"Economic Theory of Railway [illegible]

The important point in the location of hill railways was to see that they concentrated the heavy work

Not only was it a good thing to concentrate heavy work in comparatively short sections but it was also sound to concentrate their heavy grades also in short sections. This had been done on the Kangra-Valley Railway in that a 1 in 40 grade had been adopted up to Baijnath and beyond that a 4 per cent These two points were really useful and should always be remembered when faced with a hill railway location.

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[illegible] ılated for the
[illegible] He wished
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On pages 87 to 90, the alignment finally chosen is briefly described.

alignment adopted appears to be the most economical. By avoiding

[illegible]

the name, and brings Deragopipur and Hamirpur Tahsils much nearer railhead.

The alignment brings the famous Hindu shrine Jwalajee within fifteen miles of Jwalamukhi Road Station. I understand there is a project under consideration for connecting Jawalamukhi Road with Jawalajee and if completed the railway will prove a great convenience to the pilgrims.

Though there is not much to criticise in the alignment, the siting of the railway stations is not very convenient for travellers. No station [illegible]

being so far from the shrine is not much used by pilgrims, consequently the railway loses revenue. The site of the present station would have been improved by locating it between the Daulatpur tunnel and the point where the railway crosses the Jullundur-Dharmsala Road. If the Station had been sited as suggested, the approach road would have cost little, and the distance from Kangra town would have been practically the same.

As the station yard is laid out at present, every passenger has to cross the line before he can reach the platform This is not a very satisfactory arrangement.

At Jawalamukhi, Koparlahar and Kangra Stations the goods sheds have not been sited on the same side of the line as the passenger platforms and station buildings Thus, while at Kangra the approach road serves the goods-shed, at Koparlahar and Jawalamukhi Roads the approach roads only serve the passenger platforms, and the carriage of heavy goods from the goods-sheds to carts on the approach road is very inconvenient.

The Jwalamukhi Road and Koparlahar Station buildings are at a much lower level [illegible] a higher level than [illegible] e building of appro[illegible]

It is admitted that to construct a station site at Palampur would have meant an unnecessary rise and fall of about 400 feet ; and an increased length of about three miles, raising the cost of construction by several lakhs, but in view of the fact that the Punjab Government is shortly building a model town at Palampur, and the town itself is likely to prosper, it is considered that such an expenditure would have been justifiable.

On page 94, Major Waghorn has described the difficulties that he had to cope with at Paror ridge. At this point the road had been diverted, the road and railway p
at a much lower level
retaining walls in the
this big cutting.

On page 96, Major Waghorn has said that he could not obtain details of the foundations of the P W D. road bridge over the Chakki. The speaker
bridge w
tember
paper No 28 had also been written by Mr. Bagley, Executive Engineer in charge of the work These printed papers give full details of the construction of the Chakki bridge.

For the road bridge, open foundations to a level of 1255 00 about 13 feet below river bed proved sufficient, and no wells were sunk, though pumping had to be resorted to for keeping them drained.

As regards the lime cement mortar, Cement 3 : Lime 10 . Sand 27, the speaker would enquire whether any tests of strength were carried out, and what was the result.

he c
tione
estin
Bran
jects which have been completed without a great excess over the original estimates. Going as far back as 1865, the construction of the Kangra Valley Cart Road from Chakki to Palampur was started with an estimate of about 3 lacs of rupees, but up to 1874, Rs. 8 lacs had been spent and the work was still incomplete. Uncompleted portions were then taken piece by piece in accordance with funds available, and the work dragged on till about 1900, when the total expenditure incurred was well above Rs. 15 lacs. Coming to recent times, the Larji Mandi Road project was started with preliminary estimates of about Rs. 3 lacs in 1913 ending with an expenditure of about Rs. 15 lacs by 1923, and in the case of the Kangra Valley Railway it is believed that the final cost has also been greatly above that of the original estimate.

Major Waghorn, in replying stated as follows :—

As regards the details of cost of tunnel work asked for by Col. Battye, the figures given included contractors bills, *i.e.*, cost of labour and
into the work cost of works charged establishment
l the cost of fuel required for
general charges" such as pay
penses incurred in administration such as clerical and medical staff, office expenses ; it also did include the cost of plant. He considered that to get at a total

cost 7 per cent. should be added on account of "general charges" (this was the percentage figure of "general charges" taking the whole construction into account) and a further figure of 7 per cent. would more than cover the cost of plant used; this would bring the foot run costs up to approx. Rs. 620 and Rs. 553 respectively.

The second point raised by Col. Battye was in regard to depth of foundations; Col. Walton had already dealt with the subject but he would like to add a few remarks also; when referring to the figures of 12 feet which [illegible] or had in mind the series of girder [illegible] ath; he admitted that the figure [illegible] one; before the monsoon, however, boulders of varying sizes were selected and marked and their relative positions in relation to some fixed object was noted, after the monsoon a further series of observations were taken to ascertain which, if any, had moved; during the monsoon soundings, where possible, were taken to try and find out the amount of scour taking place (not a very satisfactory job in a river bed full of boulders) and certain results, chiefly negative were obtained, this data combined with a careful inspection [illegible] road bridges adjacent to the work [illegible] Walton had said a problem of this [illegible] a matter of judgment based on experience.

The author referred to a question by Col Battye regarding the centralisation of design work in the Superintendent of Works office; he agreed to the extent that a great deal of assistance could be given to [illegible] igns being [illegible] me to the [illegible] openings [illegible] that these [illegible] ie method which the author adopted, and which proved very satisfactory, was to go [illegible] had a site plan to work on

The method also proved a very quick one and the author found he [illegible]

Regarding the points raised by Mr. Brij Mohan Lal he said that the alignment from Mukerian was ruled out chiefly on account of the very expensive crossing of the Beas; the river has to be crossed very soon after reaching Mukerian and it would naturally have been impossible to carry on with the linking until this had been completed; a difficult and lengthy piece of work occurring at the lower end of a hill construction

tion such as the Kangra Valley Railway was bound to have delayed the work further up, and consequently postpone the final date of completion.

The author admitted that the station sites of Jawalamukhi, Koparlahar and Kangra were open to criticism but he thought that if Mr. Brij Mohan Lal were to study the question more closely taking into account the actual facts which had to be faced when settling these station sites he would realise that there really was no alternative There was very little room available and the siting of goods platforms on the opposite side to passenger platforms was done to close up the station yards as much as possible.

He admitted that at Paror ridge it would probably have been cheaper to have put in a "cut and cover" or a heavy section retaining wall before movement had started, but that was rather a case of being "being wise after the event."

Exhaustive tests were made regarding the strength of the lime and cement mortar but the author regretted that he was unable to give any definite figures; he can remember, however, that the results obtained were surprisingly good

superior to water bound macadam. As Highway construction and maintenance is financed almost entirely from direct and indirect taxation on motor vehicles that country would never have had such a fine Highway system today if the maximum use had not been made of earth roads ; these have been used for building up the traffic load, opening up the country and providing funds for better types of surfaces when traffic justified them.

3. In pre-motor car days or when they were comparatively few in use in India the chief destructive agents to roads were bullock carts, but as the bulk of them transported agricultural produce the number using roads had some relation to the amount of revenue of the [illegible]

[illegible] for this increased cost.

4. When taxes (direct and indirect) were first levied on motor vehicles there were comparatively few such vehicles in use which did little damage to roads, moreover as the revenue derived did not amount to a great deal, it was absorbed unnoticed into the revenues of the Government of India. To-day the taxation on motor vehicles brings in about 3 or 4 crores to Central Revenues, and this is expected to increase at the rate of 50 or 60 lakhs a year. Owing to the rapid increase in motor [illegible] age of this annually increasing revenue derived from taxation of motor vehicles is distributed among Provinces for expenditure on roads the situation will become impossible, all new construction will have to stop and existing roads will rapidly deteriorate. It would therefore seem that sooner or later a fair share of this revenue must come to the Provinces. In addition to this the Government of India has recently levied a surcharge of two annas a gallon on motor spirit for distribution among Provinces which is expected to bring in about 80 lakhs per annum, [illegible]creasing at the rate of about 10 lakhs a year. It will thus be seen that [illegible] the near future the funds available for expenditure on roads will be [illegible]derably more than what they are now and that the amount of these [illegible] will be roughly proportional to the number of motor vehicles [illegible] it is therefore [illegible] for our [illegible] the [illegible] as ra[illegible] [illegible]cy should be adopted to ensure a maximum increase per cent [illegible]ture. For instance, which would be more profitable—spending [illegible]s on building 1,000 miles of earth road at Rs. 500 a mile, or spending [illegible]ne sum on constructing 25 miles of metalled road (water bound

macadam) at 20,000 a mile; Obviously the former, there are a number of earth roads in the Punjab carrying 10 or more motor buses a day, whereas there is not a single pure water bound macadam road in India that does or could carry 400 motor buses a day The Lahore-Amritsar Road carried 250, but then it is not a pure water bound macadam road, its surface is painted with tar and costs about Rs 3,000 per mile per annum to maintain as against about Rs 70 per mile per annum for an earth road. It is not claimed that an earth road is the beginning and end of all things, but it is emphasised that the maximum use should be made of it, as it produces revenue for better type of roads, feeds railways, helps the agricultural *and the motoring public, and opens up the country rapidly and* economically.

PUNJAB.

Roads in Punjab are divided in 4 classes. (1) Arterial, (2) Class II or Main, (3) Class III, (4) Village.

Arterial Roads.—Comprise, as the name suggests, such roads that [illegible] population [illegible] 4,720, of [illegible] maintained [illegible]

Class II or Main Roads.—These include roads that pass through more than one district, connect towns with a population of over 5,000, link up important pilgrim shrines, and trading centres with mandis, arterial roads, railways or with one another. They are maintained by District Boards from their own resources aided by grants-in-aid from Government, the latter is distributed by the Communications Board. The total mileage under this head is 8,160, of which 1,151 are metalled and 7,009 are unmetalled.

Class III Roads.—Include all other roads (excluding village roads) in districts and are maintained by District Boards entirely from their own resources. There is no accurate record of the exact mileage, but it is believed to be 11,000, of which 150 miles are metalled.

Village Roads.—These are mere connecting links to the Highway [illegible] absorbed by encroachment are mere drains and are absolutely impassable in the wet weather. There is no record of their mileage but is said to be 40,000 miles.

every year. If the opening up of the country is to depend entirely on metalled roads and the same metalling programme can be maintained it will take well over a century. Moreover owing to the increase in motor traffic and the consequent increase in the cost of maintenance of metalled roads it is exceedingly doubtful whether the present metalling programme can be maintained. It would, therefore, seem that at the present time the Province cannot afford a large increase in metalled mileage, and until it becomes a great deal richer, development will have to depend mainly on unmetalled roads and moreover as in the case of America, these very unmetalled roads, now largely ignored, are going to provide the money for building and maintaining better roads in the future.

As early as 1921, the Communications Board of the Punjab realised the very great importance of unmetalled roads and have been impressing

these roads were already in existence, so the work really consisted of improvement; this consisted of restoring the camber by about 6" to 8" earth filling, watering and rolling, repairing existing culverts and providing new ones where necessary. To give the experiment a fair trial the Communications Board entirely financed the cost of improve-

factory, this method proved comparatively expensive, improvement costing Rs. 1,500 a mile and subsequent maintenance about Rs. 200 a mile. Therefore activities in this direction were somewhat restricted until the introduction of tractors and graders described in detail hereafter and sufficient successful work has been done to predict with some measure of certainty that the use of road grading plant will go a long way towards solving our road problems and further owing to the low cost of maintenance we can look forward to seeing the Province opened up at a very rapid rate. During the space of two years nearly 2,347 miles of earth roads will have been improved and if this progress can be maintained, it is not difficult to visualise the extent of the benefit that will accrue in a very short time.

SOIL ANALYSES AND ESTIMATES.

As already stated the present condition of most demonstration roads clearly showed that where earth roads received adequate attention and where the soil was suitable, they could be kept in such good condition as to permit a motor vehicle to travel over them at about 25 miles an hour. Unfortunately the quality of soil not only varied in different districts but in many cases in different places on one road, therefore whatever method (machinery or manual labour) was adopted for the maintenance of unmetalled roads even a moderate measure of success could not be obtained unless suitable soil was transported to places where the soil was bad The first objective was therefore to ascertain what exactly was unsuitable soil and whether the transportation of soils was a practical proposition A rapid reconnaissance made in a few districts showed straight away that the number of miles containing unsuitable soil was comparatively small and that carting good earth where it was needed was neither difficult nor expensive. It was therefore decided to make a soil analysis survey of all Class II unmetalled roads in the Province and to ascertain by observation and experiment the behaviour of various classes of soil under traffic. Observations showed that from the point of view of earth roads soil could be conveniently divided into the following four classes.—

(1) A soil containing not more than 30% of sand and 70% clay made a first class unmetalled road which could stand up to heavy traffic if properly maintained.

(2) A soil containing between 30% to 40% sand and the balance clay made a moderately good road, but was liable to break up under heavy traffic.

(3) A soil containing over 40% of sand was of no practical value for roads, it was found necessary to blanket such soil with good earth to render it fit for traffic

(4) Soil containing saltpetre was of two classes—

(*a*) where excess of salts were deposited on the surface due to capillary attraction and subsequent evaporation;

(*b*) where the soil was merely impregnated with salts. *The former is quite unsuitable for earth roads but* can be treated in a similar way to Class III soil, the latter is excellent for earth roads, it tends to attract moisture, readily compacts and presents a hard surface.

[illegible]

Province. Therefore classification had to be done by eye trained for the purpose. It was found by experience that after a Subordinate had analysed 40 or 50 samples he was able to tell by casual inspection what percentage of sand any soil contained. Saltpetre of the 4 (*a*) variety is [illegible]

[illegible]

the improvement estimates were prepared. The abstract of these estimates as well as soil analyses of 2,603 miles of Class II unmetalled roads [illegible]

[illegible]

all transportation charges of good soil where necessary.

ROAD GRADING IN THE PUNJAB.

History.

There are no accurate records regarding the early history of road grading in the Punjab, but it is said to have started with the purchase of a light Western Grader (weighing about 1,800 lbs.) about the year 1921. The original idea was to use animal power to haul the machine, but this was soon found to be very unsatisfactory, bullocks would never keep straight and it was very difficult to hire them when they were most needed, *i.e.*, during the rains Therefore except for some experiments, about which there is no record, using a borrowed Fordson Tractor to haul it the grader seems to have been laid aside for a number of years; anyway judging from its condition at the end of 1927 the machine appears to have seen a good deal of service Interest in road grading was revived when the following plant was purchased at the end of 1927.

(1) A Fordson Tractor to haul the light Western Grader.

(2) A No. 3 Standard Russell grader weighing 4,200 lbs. to be hauled by a 35 H P. Hercules Steam Tractor.

Outfit I.—Though the grader was not in too good condition, the blade was blunt and the bearings of the wheels had worn out badly, experiments carried out in Gujranwala early in 1927 established straight away that this type of outfit had great possibilities for maintenance of earth roads that had been improved, but was much too light to do any improvement work, it tended to ride over rather than shave off hard spots; however as there were so few roads at that time in an improved condition there was little scope for it.

Outfit II.—This was a very much heavier combination and primarily intended for heavy improvement work, and just what was needed at that time. A factory representative of the Russell grader Company was sent out specially to demonstrate how to operate the grader and to shape earth roads. He remained at Hansi in Hissar District for about 10 days, improved about 3 miles of earth road himself and initiated the writer, his assistants and the local District Board staff into the mysteries of road grading This outfit continued to do splendid work for about a month when the shaft of the 2nd gear pinion (about 3" in diameter) suddenly snapped, a new shaft was fitted and this behaved in exactly the same way after a few days work After close investigation it transpired that the tractor was quite unsuitable for heavy road grading as it was under powered and too high geared. Though the plant has continued to work from time to time it has never been satisfactory.

Several other machines were also purchased by Government for construction and maintenance of earth roads in the Nili Bar Colony but a great deal of use has not been made of them, partly because the soil in this area was not suited to earth roads, and the plant was not really what was wanted Experience gained at this stage clearly showed that road grading had a great future but the machinery at our disposal was not really suitable.

SELECTION OF PLANT, ETC.

Though it was felt that experiments with other types of plant were immediately necessary, it would be folly to purchase any more plant without ascertaining by experience what was really needed. These considerations led to the introduction of what was called "Working [illegible] basis" in about July 1928 that is firms [illegible]ted in [illegible] inery [illegible] sum [illegible] was assumed for the tractor and four years for the grader.

Four firms were enterprising enough to agree to these conditions and the following two outfits placed at the disposal of District Boards and commenced working in July-August 1928.

III. A No. III Highway Patrol weighing 1,800 lbs. drawn by a 12/20 H. P. Case Tractor.

IV. A Howard Grader weighing 4,000 lbs. (equipped with a 7' maintenance blade as well as a 12' maintenance blade) drawn by a 15-30 H. P. Nacormak Deering Tractor.

(A No. 7 leaning wheel Adams Grader was subsequently placed at the disposal of Disitrict Boards on the same conditions).

The object of this arrangement was fourfold :—

(*a*) To ensure the plant was properly handled.

(*b*) To train both supervising and operating staff how to run these machines.

(*c*) To ascertain the correct type of plant to be used.

(*d*) To demonstrate to District Boards the advantages of using road machinery for earth roads as opposed to manual labour and to eventually persuade these local bodies to purchase outfits of their own.

As far as (*a*), (*b*) and (*c*) are concerned the objects have been attained [illegible]

[illegible] training and it has been definitely established that for reshaping [illegible]

[illegible] ably give slightly better results but there will be difficulty about securing a powerful enough tractor. A tractor of about 15 (draw bar) H. P. is the most powerful in general use in India for which spares and service is readily available and the heaviest grader that can be hauled by such a [illegible] about 4,000 lbs. Therefore as far [illegible] the outfit that has been selected as being the most suited to the Punjab is a 15 (draw bar) H. P. coupled to a grader weighing 4,000 lbs.

Though these heavier machines now perform the dual function of heavy grading and maintenance, it is the ultimate aim that each District Board will have one or more light maintenance set as well as a heavy outfit. The two maintenance outfits with graders weighing about 1,800 lbs. have given satisfaction but experience in America points to the conclusion that much better results will be obtained by using a special machine known as a maintainer, and it is proposed to experiment with it very shortly. This machine operates on a slightly different principle to that [illegible]

Progress.—As the result of these demonstrations object (*d*) has in a large measure been attained, there are only perhaps 4 or 5 District Boards in the whole Province that are not thoroughly convinced that road grading is the most economical and efficient method of reshaping and subsequently maintaining an earth road. Thirteen District Boards have purchased outfits of their own which are at work, two have actually ordered outfits so that 15 districts, more than half the number of districts in the Province, will have tractors and graders working presently. These

exclude the demostration outfits which will be used in districts not yet convinced or who cannot afford their own plants In addition to these, three districts are thinking of purchasing their second outfits.

The enterprise of these four firms have certainly borne fruit and have been responsible for the birth of road grading in the Punjab, and in consequence Government has now decided to purchase these demonstration outfits from the firms concerned at cost price minus what has already already been paid by District Boards on account of depreciation.

Maintenance of Plant.

To ensure that the plant was properly handled, the supervising and operating staff of District Boards were properly trained before assuming complete control, and to safeguard District Board's interests the suppliers of new road machinery were expected to run the plant for six months with their own staff, District Boards paying actual running expenses and if the plant proved satisfactory District Boards were expected to purchase it.

From the point of view of the suppliers these conditions appear

period of six months the District Engineers and their supervising staff were trained to operate the plant with their own hands. A daily log is maintained for each outfit showing fuel and other stores consumed and work done, this enables the Engineer Secretary of the Communication Board to keep in very close touch with the performance of each machine. In addition frequent inspections are made by Assistant Engineers and the Mechanical Overseer of the Communications Board as well as by the engineers and mechanics of the suppliers, by this means those in local control are kept up to the mark and serious break downs have been reduced to a minimum

Graders.—Except for the Howard grader which is really an experimental machine and gave a certain amount of trouble until defects were rectified, no great difficulty was experienced with their working once the operators got accustomed to them Of the meachines used so far the No. 7 Adams grader is perhaps the best, its controls are very easy to operate and it is fitted with leaning wheels, this reduces the tractor

models in use a No. 3 standard weighing 4200 lbs, a No. 2 standard weighing 3,000 lbs. perhaps a bit too light for heavy grading, and a No. 3 Highway Patrol weighing 1 800 lbs. Both the standard models have suitable scarifier attachments.

Tractors.—The whole business of road grading hinges on the efficient and continuous working of tractors, and considering how easy it is to wreck a tractor, and the lack of knowledge and experience of the operating staff it is most surprising that such consistently good results have been attained—accidents there have been but surprisingly few.

[illegible]

and fixing a safety catch on the draw bar coupling of the tractor.

Among the tractors of which we have record of performances are—

5 No. 15-30 H P. Macormack Deering Tractors.

2 No. 18-32 H. P. Case Tractors.

1 No. 12-20 H. P. Case Tractor.

It is early to express any opinion on the relative merits of the two makes of tractor as the maximum time worked by any Macormack Deering is about 1200 hours and that of any 18-32 H.P. Case is less than 500 hours, both have worked satisfactorily so far. The 12-20 H. P. Case has not proved very satisfactory for road grading as it is underpowered though it does not show up too badly in running costs (excluding establishment and depreciation). Moreover it was shockingly overloaded at times.

A list of plant used and the detailed cost of working the tractors [illegible]

which corresponds to only 172 working days in a year, a poor average. We should reckon on about 200 or more with more experience in handling the machines and better planning out of the programme of each outfit. The performance of the Ambala outfit is very disappointing, the cost of running at 2·12 per mile, excluding depreciation and establishment, is very high and is not entirely accounted for by the high repair bill.

The cost of operating the outfits (excluding depreciation and establishment) will increase as the outfits become older so that even though Rs. 4 per working day has been allowed for replacements, it would be safer to allow Rs. 4 per mile for the purpose of calculations.

PROCESS OF IMPROVING THE SURFACE OF EARTH ROADS.

Manual Labour.—Whether we use machinery or not there are certain items of work that must be done by manual labour and they are as follows :—

(*a*) Repairing or constructing bridges, culverts causeways, etc., and improving the approaches to them

(*b*) Filling all places liable to flood and where big holes and depressions occur

(*c*) Blanketing with 6″ of good earth all stretches containing unsuitable soil, an alternative is to grass the surface but this is expensive to maintain.

(*d*) Removing jungle and other obstructions

(*e*) Providing milestones consisting of 3″ × 3″ angles 4 feet long

The essential difference between work done by machinery and manual labours lies in cambering and improving the surface, the latter involves obtaining earth from borrow pits and the former does not, therein lies the main source of saving.

Grading Operations.—Generally speaking all earth roads have not only lost their camber, but the centre is very much lower than the sides through years of neglect. There is no outlet for the water which soaks into and softens the soil, the surface is therefore readily [illegible]

where the rainfall is light and most months of the year are dry excessive earth filling may take a year or more to settle, and in the interval of [illegible]

First Round of Grading consists of making a 4″ to 6″ deep (maximum) cut at an angle of 1 in 30 on either side of a road Only 1/3rd of the width is graded on each side and the middle third filled with earth from the sides. As the filling in the centre is not excessive it quickly settles down. Moreover after the 1st grading is done traffic is generally attracted by the two graded strips at the sides which is hard and smooth. It is generally necessary to run the grader eight or ten times up and down a road during the first round.

Second Round of Grading.—An appreciably lighter cut is made on this occasion and the sides are still further lowered and the centre

raised and the road begins to assume some semblance of shape but as the centre is still loose, and water can saturate the soil, the surface is quickly cut up by traffic. Nevertheless the road does not generally lose its shape. This round only requires about six to eight gradings.

Third Round of Grading consists of making a still lighter cut for the purpose of filling up ruts, and depressions that have occurred through settlement. This round only requires four to six gradings Experience shows that the road remains in good condition from eight to ten weeks after this round depending on soil conditions and traffic.

Cost of Improving the Surface and Restoring camber per mile.

Ist round of grading nine miles of travel at 4/-	..	=36
2nd round of grading seven miles of travel at 4/-	..	=28
3rd round of grading five miles of travel at 4/-	..	=20
Total	..	84
Add 10% for movement of plant when no work is done	..	8·4
		92·4
	say	95/-

Maintenance.—This consists of making three gradings at the following five periods in the year, December-January, February-March, June-July, August,-September, October-November and has been found sufficient to keep earth roads in good order under average soil and traffic condition. In normal years we can safely reckon on sufficient moisture being in the ground in three periods out of five February-March and October-November is inclined to be troublesome on account of dust, but this is difficult to avoid under the climatic conditions of the Punjab unless watering is done just before grading. Investigations are being made and experiments carried out to ascertain the possibilities of watering roads before grading in the dry periods, and information available at present seems to show that watering will not increase the cost of maintenance by more than Rs. 20 to Rs 30 per mile per annum.

Cost of maintenance, three miles of travel, five times a year	..	=15
Add 10 % movement of grader when no work is done	..	1·5
		16·5@4/- =66
		say 70 per mile.

TRANSPORTATION ON EARTH ROADS.

Passengers.—Hitherto motor buses have been confined to metalled roads but during the last few months these vehicles are now making use of not only the newly graded roads but are beginning to use earth roads even before improvement. The average number of buses using earth roads in various districts is given in Appendix No. II. These figures show that nearly 500 travel on 124 roads daily which averages out at four per road. No census of figures have been received from Multan, Shahpur, Montgomery and Gujranwala where it is known a large number of motor buses use earth roads It is therefore reasonable to assume that the number of buses is nearer 600 than 500.

Except in Karnal, Gujrat and Sheikhupura districts the mileage on which motor buses run is appreciably larger than the actual number of miles improved, this figure appears to establish that travelling by motor buses even on earth roads is becoming more popular that there is a growing demand for more such roads, which at present carry about two million passengers annually.

Generally speak
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miles to the gallon, even for a 3/4 ton bus the type in general use on earth roads. It is therefore reckoned that each of these vehicles consume about 650 gallons per annum. By virtue of the newly imposed 2 annas a gallon tax on motor spirit each of these buses will contribute $\frac{(650 \times 2)}{16}$ Rs. 80/- per annum to Provincial Revenues, in addition there is a charge of Rs. 80/- per annum on account of the Provincial tax and road certificate.

the general average is about 50 or 60. We could therefore safely increase the number of buses now plying on these roads to four times their present number. Therefore if the number of motor buses increases to this extent, of which there is every indication, motor buses plying on these particular 124 roads will contribute nearly two lakhs towards Provincial Revenues against only (2,000 × 70) 1 4 lakhs required for proper maintenance. It follows that it is not only necessary to increase the mileage of earth roads as much as possible but to encourage motor buses to use them.

Goods.—It has been shown that up to the limit of their carrying capacity the more motor vehicles that used earth roads the greater the benefit to the Province, and moreover if it were possible to replace th-

raised and the road begins to assume some semblance of shape but as the centre is still loose, and water can saturate the soil, the surface is quickly cut up by traffic. Nevertheless the road does not generally lose its shape. This round only requires about six to eight gradings.

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3rd round of grading five miles of travel at 4/-	..	=20
Total	..	84
Add 10% for movement of plant when no work is done	..	8·4
		92·4
	say	95/-

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[illegible] roads before grading in the dry periods, and information available at present seems to show that watering will not increase the cost of maintenance by more than Rs 20 to Rs. 30 per mile per annum.

Cost of maintenance, three miles of travel, five times a year	..	=15
Add 10 % movement of grader when no work is done	..	1·5
		16·5@4/- =66
	say	70 per mile.

TRANSPORTATION ON EARTH ROADS.

Passengers.—Hitherto motor buses have been confined to metalled roads but during the last few months these vehicles are now making use of not only the newly graded roads but are beginning to use earth roads even before improvement. The average number of buses using earth roads in various districts is given in Appendix No. II. These figures show that nearly 500 travel on 124 roads daily which averages out at four per road. No census of figures have been received from Multan, Shahpur, Montgomery and Gujranwala where it is known a large number of motor buses use earth roads. It is therefore reasonable to assume that the number of buses is nearer 600 than 500.

Except in Karnal, Gujrat and Sheikhupura districts the mileage on which motor buses run is appreciably larger than the actual number of miles improved, this figure appears to establish that travelling by motor buses even on earth roads is becoming more popular that there is a growing demand for more such roads, which at present carry about two million passengers annually.

[illegible] a day [illegible] a for [illegible] about 500. Petrol consumption is generally heavy, not less than 15 miles to the gallon, even for a 3/4 ton bus the type in general use on earth roads It is therefore reckoned that each of these vehicles consume about 650 gallons per annum By virtue of the newly imposed 2 annas a gallon tax on motor spirit each of these buses will contribute $\frac{(650 \times 2)}{16}$ Rs. 80/- per annum to Provincial Revenues, in addition there is a charge of Rs. 80/- per annum on account of the Provincial tax and road certificate. [illegible] of these buses contribute Rs. 160/- per annum to Provincial [illegible] 000/-. Observation shows [illegible] maintenance gradings per annum will be sufficient to keep an earth road, carrying 15 motor buses and 100 bullock carts daily in quite good order. There are very few unmetalled roads in the Province that carry 100 bullock carts a day, the general average is about 50 or 60 We could therefore safely increase the number of buses now plying on these roads to four times their present number. Therefore if the number of motor buses increases to this extent, of which there is every indication, motor buses plying on these particular 124 roads will contribute nearly two lakhs towards Provincial Revenues against only (2 000×70) 1 4 lakhs required for proper maintenance. It follows that it is not only necessary to increase the mileage of earth roads as much as possible but to encourage motor buses to use them.

Goods.—It has been shown that up to the limit of their carrying capacity the more motor vehicles that used earth roads the greater the benefit to the Province, and moreover if it were possible to replace the

bullock cart by goods lorries a great benefit would not only accrue on account of taxes they would pay as in the case of passenger buses but maintenance costs would be reduced as a pneumatic tyred lorry would damage an earth road less than a bullock cart. The greatest obstacle to the more extended use of motor vehicle for the transportation of goods is the deplorable state of village roads. Unless the latter are improved very little progress in this direction can be expected as double handling of goods will be involved. Moreover the cost of transporta-

at 6 annas a ton

uch the same. It is

hicle will ever oust

the bullock cart from carrying goods especially as the number of agriculturist using the same bullocks for ploughing and transportation is very

The cheap transportation of goods throughout the British Empire has been engaging the attention of the Empire Marketting Board and as the result of their endeavours a Directing Committee was appointed by the Secretary of State for Dominion Affairs and for Colonies (of the late Government) at the end of October 1928 with the following terms of reference :—

" ... further the

econom

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low c

types of vehicles in use

it has been realised that

provement of design there

purpose.

The trend of investigation seems to suggest hauling one or more trailers with several pairs of wheel shod with large pneumatic tyres may be a suitable unit.

Experiments are being carried out with--

(*a*) Various engines using Diesel oil or producer gas.

(*b*) Various types of trailers with pneumatic tyres.

(*c*) Various types of pneumatic tyres, one particular experiment deals with a tyre particularly designed to soft roads in which deep ruts occur.

(*d*) Various types of metal tracks.

Considerable progress has been made towards the production of a 15-ton unit consisting of a tractor hauling a number 8-wheel trailers.

It is expected that experiments with a 50-ton unit will be carried out in the near future.

As far as the Punjab is concerned experiments with 50-ton unit will be of purely academic interest (our bridges will not be strong enough) a 10-ton unit will be nearer the measure of the capacity of our bridges. Developments with the smaller unit will be watched with a good deal of interest as it will fit in admirably with the scheme of improving earth roads.

Judging from the extensive experience gained in operating agricultural models of kerosine-driven tractors on road grading in the Punjab it would seem that a suitable transportation unit for earth roads might [illegible]

be possible to transport by this means at 4 as a ton mile, eventhough the unit only worked 800 hours in the year (the average duration of the period in which agricultural produce is carted to market) and obtained no return loads. Unless earth roads were converted to and maintained as gravel roads, it would not be safe to rely on obtaining return loads, but it is fairly certain that the tractor by itself, the whole unit, or even the establishment could be employed during idle periods, thus appreciably bringing down the percentage of fixed charges. It is therefore very [illegible]

even more cheaply.

Selection of Surfaces.—Even though a good beginning has been made in the Punjab, where a beginning should have been made years ago, [illegible] earth roads there [illegible]

maximum use of our resources, to lay a road with a surface that costs say, a Rs. 600/- or Rs 700 - to maintain when the traffic that was likely to use [illegible]

country, and the selection of surfaces were governed by the volume of traffic, it would be found that there are hundreds of miles of metalled roads that are not justified and a correspondingly large mileage of earth roads that ought to have a superior surface It is most essential that intermediate type of surfaces between an earth road and a metalled road should be introduced and their carrying capacity determined so that [illegible]

bullock cart by goods lorries a great benefit would not only accrue on account of taxes they would pay as in the case of passenger buses but maintenance costs would be reduced as a pneumatic tyred lorry would damage an earth road less than a bullock cart. The greatest [illegible]

tion of goods by say, a ton or 30 cwt lorry figures out at 6 annas a ton mile, the transportation by bullock cart is pretty much the same. It is therefore unlikely that the present type of motor vehicle will ever oust the bullock cart from carrying goods especially as the number of agriculturist using the same bullocks for ploughing and transportation is very great. Unless therefore the cost of transportation of goods by mechanical means could be reduced to say, 3 annas a ton mile, the bullock cart will continue to hold its own.

The cheap transportation of goods throughout the British Empire has been engaging the attention of the Empire Marketting Board and as th[illegible]
by th[illegible]
late [illegible]
reference :—

" To study every aspect of mechanical transport likely to further the economic development of the Empire " The main objective was to produce a unit of large carrying capacity capable of transporting goods at low cost on earth roads without unduly damaging them. This committee has carried out investigations on existing types of vehicles in use or those projected throughout the world, and it has been realised that though immense strides have been made in improvement of design there is no vehicle in existence that will serve this purpose.

The trend of investigation seems to suggest hauling one or more trailers with several pairs of wheel shod with large pneumatic tyres may be a suitable unit.

Experiments are being carried out with--

(*a*) Various engines using Diesel oil or producer gas.

(*b*) Various types of trailers with pneumatic tyres.

(*c*) Various types of pneumatic tyres, one particu'ar experiment deals with a tyre particularly designed to soft roads in which deep ruts occur.

(*d*) Various types of metal tracks.

Considerable progress has been made towards the production of a 15-ton unit consisting of a tractor hauling a number 8-wheel trailers.

It is expected that experiments with a 50-ton unit will be carried out in the near future.

As far as the Punjab is concerned experiments with 50-ton unit will be of purely academic interest (our bridges will not be strong enough) a 10-ton unit will be nearer the measure of the capacity of our bridges. Developments with the smaller unit will be watched with a good deal of interest as it will fit in admirably with the scheme of improving earth roads.

Judging from the extensive experience gained in operating agricultural models of kerosine-driven tractors on road grading in the Punjab it would seem that a suitable transportation unit for earth roads might possibly consist of such a tractor (15 H. P.) ...
an hour on top, and 100 pneuma...
Calculations (attached *vide* Append...
be possible to transport by this means at 4 as. a ton mile, eventhough the unit only worked 800 hours in the year (the average duration of the period in which agricultural produce is carted to market) and obtained no return loads Unless earth roads were converted to and maintained as gravel roads, it would not be safe to rely on obtaining return loads, but it is fairly certain that the tractor by itself, the whole unit, or even the establishment could be employed during idle periods, thus appreciably bringing down the percentage of fixed charges. It is therefore very ...

even more cheaply

Selection of Surfaces.—Even though a good beginning has been made in the Punjab, where a beginning should have been made years ago, ...

maintain, even the cost of the proper maintenance of kankar roads 9′ wide is beginning to approach this figure under present-day traffic conditions. With the limited funds at our disposal it would not be making the maximum use of our resources, to lay a road with a surface that costs say, a Rs. 600/- or Rs 700/- to maintain when the traffic that was likely to use it for the next four or five years would probably not exceed twice the carrying capacity of an earth road In India the value of a traffic census has not been fully appreciated, if such were taken on all roads throughout the country, and the selection of surfaces were governed by the volume of traffic, it would be found that there are hundreds of miles of metalled roads that are not justified and a correspondingly large mileage of earth roads that ought to have a superior surface It is most essential that intermediate type of surfaces between an earth road and a metalled road should be introduced and their carrying capacity determined so that ...

[illegible] Therefore [illegible] heikhupura [illegible] ad on two [illegible] was small, [illegible] d. In the [illegible] overburnt [illegible] In both c [illegible] appreciably over 3 [illegible] the experiments v [illegible] road has recently been laid on the approach to the new Railway Station of Rupar at a very low cost as gravel was obtained locally and the results obtained so far are promising.

[illegible] a gravel road is an [illegible] ad are being so con [illegible] road have been carried out in this country; road oils are expensive, it is therefore not definitely certain whether such a road would be a practical proposition. Experiments are however now being carried out with a cheaper and improved form of surfacing for metalled roads ; it is expected that a type of surface will be devised that is much cheaper to renew than water bound macadam and yet have an appreciably longer life; if these expecttations are fulfilled then this will probably be the third stage of development of surfaces.

APPENDIX I.

Statistics of Road Mileages and Motor Vehicles of Main Countries in the World.

Country.	Road Mileages				No. of Motor Vehicles		
	Earth or gravel	Surfaced	Total.	Percentage of surfaced	Total.	Per mile.	Persons per vehicle.
	1	2	3	4	5	6	7
1. Argentina .	18·6	4	19·0	2·1	268·0	14·0	37·3
2. Brazil .	46·5	4	46·9	9	136·8	2·9	223·9
3. Canada .	417·1	6·9	424·0	1·6	957·1	2·3	9·8
4 Chile ..	22·2	2·6	24·8	10·5	19·4	8	202·7
5. Mexico	1·2	3	1·5	20·0	57·6	37·7	268·7
6. United States .	2·4	6	3·0	20·0	24·0	8·0	5·1
7. British East Africa (see also Jubaland)	13·7	2·7	16·4	16·5	14·0	8	831·3
8. Egypt	3·2	1	3·3	3·0	25·1	7·5	563·7
9. South Africa (excluding the Union).	7·3	4	7·7	5·2	7·5	9	366·6
10. South Africa, Union of	67·4	6	68·0	9	133·2	1·9	53·1
11. Ceylon .	11·0	4·8	15·8	30·4	17·3	1·0	288·9
12. China	17·3	4	17·7	2·3	23·8	1·3	18,744·7
13. India	150·7	60·3	211·0	28·6	109·9	5	2,900·1
14. Japan	72·7	1	72·8	1	72·5	1·0	881·4
15 Turkey (including Turkey in Europe)	18·5	3	18·8	1·6	7·4	4	1,844·6
16. Austria ..	6	20·6	21·2	97·2	51·6	2·4	126·4
17. Belgium ..	..	6·3	6·3	100·0	139·0	22·0	56·7
18. Denmark ..	28·0	4·0	32·0	12·2	105·9	3·3	

APPENDIX I.—*concld.*

Country.	Road Mileages.				No of Motor Vehicles		
	Earth or gravel	Surfaced	Total.	Percentage of surfaced.	Total.	Per mile.	Persons per vehicle.
	1	2	3	4	5	6	7
19. France .	415 4	24 6	440 0	5 6	1,114 0	2 5	36 6
20. Germany .	102 6	25 6	128 2	20 0	861·0	6 8	73 4
21. Greece ..	4 6	1·8	6 4	28 1	14 3	2 2	416 0
22. Hungary .	22 1	8 6	30 7	28 0	17 9	·6	472 3
23. Irish Free State ..	..	46 7	46 7	100 0	44 6	1 0	381 7
24. Italy ..	27 2	86 4	113 6	76 0	212·1	1·9	191 2
25. Netherlands ..	.	10 8	10 8	100 0	102·8	9 5	73 2
26. Northern Ireland ..	..	12 9	12 9	100 0	30 8	2 4	108 6
27. Norway .	22 5		22 5	.	38 0	1 7	73 3
28 Rumania	22 3	32 4	54 7	59 2	21·7	·4	789 0
29. Russia (including Russia in Asia).	415 1	15 1	430 2	3 5	25 8	·06	5,690 9
30. Spain ..		50 0	50 0	100 0	194 2	3 9	1,121·1
31. Sweden ..	80 2	5	80 7	6	147 8	1 8	42 4
32. Switzerland		8 4	8 4	100 0	85 0	10 0	46 6
33. United Kingdom .		178 7	178 7	100 0	1,856 7	10 4	23 8
34. Australia	319 9	40 1	260 0	11 1	508 2	1 4	12 3
35. New Zealand ..	*	44 3	44 3	..	169 4	3 6	8 0

* Figures not available.

Note.—Figures in columns 1, 2, 3, 5 shown in thousands.

Note.—In the year 1904 there were 55,000 Motor vehicles and 1,54,000 miles of surfaced roads in the U. S. A.; therefore in the space of 25 years the surfaced mileage has increased nearly four times while the number of Motor vehicles has increased nearly 430 times.

APPENDIX No II.

Statistics regarding Motor Buses plying on Class II Unmetalled Roads in the Punjab

No	District	Roads used — Mileage	Roads used — No of roads	Mileage of road improved	No of Motor Buses — Total	No of Motor Buses — Per road
1	Hissar	249	15	110	44	2 9
2	Rohtak	..	.	14	.	.
3	Gurgaon	.	..	12	.	.
4	Karnal	37	3	50	1	·3
5	Ambala	87	6	60	28	4 6
6	Simla	.	..	..	..	..
7	Kangra	.	..	.		.
8	Hoshiarpur	165	6	24	25	4 1
9	Jullundur	50	2	7	10	5 0
10	Ludhiana	22	1	12	1	1 0
11	Ferozepur	140	10	60	16	1 6
12	Lahore	15	1	15	5	5·0
13	Amritsar	122	7	44	37	5 2
14	Gurdaspur	140	10	80	86	8 6
15	Sialkot	147	6	116	11	1 8
16	*Gujranwala*	Census report not received				
17	Sheikhupura	124	18	145	74	4 1
18	Gujrat	81	9	106	33	3 6
19	Shahpur	Census report not received				
20	Jhelum	Census report not received.				
21	Rawalpindi	Census report not received				
22	Attock	107	8	72	40	5 0
23	Mianwali	45	2	4 5	15	7·5
24	*Montgomery*	Census report not received				
25	Lyallpur	180	8	120	20	2 5
26	Jhang	154	6	116	31	5 1
27	Multan	Census report not received				
28	Muzaffargarh	103	6	90	20	3 3
29	Dera Ghazi Khan	Census report not received.				
	Total	1,968	124	1,257 5	497	4 0

APPEN

Detail of Cost of Work

District.	Name of Plant.	1 Period. From	To.	No of days	2 Actual Working Time. Days	Hours	Hours p diem	3 Miles Travelled. Total	Per Diem.	4 Fuel Oil. Gallon	Cost.
[illegible]	[illegible] ing 4,[illegible]00 lbs.	[illegible]	[illegible]	233	107	618 5	7 6	1,632	15 2	1598	1506
2 Ambala	15-30 H. P. McCormick Deering Tractor. No. 7 Adams, Leening Wheel Grader weighing 4,000 lbs.	July 1929	September 1929.	75	49	279 5	5 7	784	16	890	833
3 Karnal	15-30 H P. McCormick Deering Tractor. No. 3 Standard Russell Grader weighing 4,200 lbs	April 1929.	August 1929	153	51	421 5	8 3	717·25	14	724	632
4 Ferozepur	18-32 H P Case Tractor .. No 2 Standard Russell Grader weighing 3,000 lbs.	April 1929.	June 1929	74	56	339 5	6 1	767	13 7	756	674
5 Lahore	15-30 H P. McCormick Deering Tractor. Howard Grader weighing 4,000 lbs.	December 1928.	January 1929.	31	18	134	7.4	283	15 7	178	216
6. Sheikhupura.	12-20 H. P. Case Tractor Russell Highway Patrol No 3 weighing 1,800 lbs.	August 1928.	January 1929.	164	71	437·5	6 2	587 5	8 3	536	515
Ditto.	15-30 H.P.McCormick Deering Tractor. Howard Grader weighing 4,000 lbs.	July 1928	February, 1929	243	101	771 25	7 6	1210 0	12 0	1,201	1,145
7. Gurdaspur	15-30 H P. McCormick Deering Tractor No 7 Adams, Leening Wheel Grader weighing 4,000 lbs.	June 1929	August 1929.	78	44	316 0	72	623 0	14·2	585	512
8 Jhang	18 32 H. P. Case Tractor. No 2 Standard Russell Grader weighing 3,000 lbs	April 1929.	August 1929.	153	72	486 5	6.7	987 25	13 9	755	673
	Grand Total ..			1,204	569	4,004	7 0	7,590	13 3	7,223	6,708

DIX No III
ing Tractors and Graders

WORKING COST.

5		6		7	8	9	10	11	12	13	14
Lub oil		Petrol		Running repairs	Miscellaneous	Total	Cost per mile	Establishment	Dep & Repl	Grand Total	Cost p mile tr
Gallons	Cost	Gallons	Cost								
140	599	31 5	51		161	2,317	1 42	1,340	1,658	5,315	3 26
48 5	170	16	28	238	336	1,665	2 12	431	760	2,856	3 64
69	263	16	27		8	930	1 29	850	1,790	2,600	3 62
44	227	18 5	30	11	21	963	1 25	426	868	2,257	2·94
31	124	10	15	2	2	359	1 23	178	279	816	2 88
62 5	263	30	46	24	65	913	1 55	943	1,100	2,956	5 03
110 5	478	50 5	76	42	49	1,790	1 48	1,397	1,565	4,752	3 92
33	158	11 6	18		7	695	1 11	449	1,680	1,824	2 9[illegible]
40·5	147	22 5	38	260	20	1,140	1 15	880	1,116	3,136	3 18
588	2,429	206·0	329	577	29	10,772	1 42	6,021	8,810	26,512	3 60

REMARKS

1 *Establishment—*

	per mensem Rs.
Driver	100
Grader Operator	40
Coolie	15
Chaukidars	15
Total	170 or

say Rs 5-12-0 per diem

2 *Depreciation and Replacements—*

The cost of the plant used in different districts vary and include experimental plant that will not be used in the future Therefore the charge under this head is based on cost of plant that has been found suitable A life of 500 days has been assumed for the Tractor and 1,000 days for the Grader.

Plant	Cost.	Depreciation per diem
Grader	3,350	3·35
Tractor	4,650	9 30
Total		12·65
Add for Replacements of Parts		3 00
Total		15 65

or say Rs 15-8-0 per diem

NOTE Item I is spread over the period of working (Col. I)

Item II is confined to the actual No. of days worked (Col. II).

APPENDIX IV.

Demonstration earth roads in the Punjab.

District.	Name of Road	Mileage.	Present condition
Hissar ..	(1) Hansi-Sissai ..	4	
	(2) Hansi-Bhiwani	6	
Rohtak ..	Sonepat-Gohana ..	10	Good.
Gurgaon ..	Ballabgarh-Chhainsa .	12	
Karnal .	Karnal-Hansi .	2	
Ambala ..	Ambala-Naggal .	10	Very poor, soil unsuitable
Hoshiarpur .	Jadla-Balachaur	5 26	
Jullundur .	Nawanshahr-Jadla	7 15	
Ludhiana .	Ludhiana—Raikot :	10	
Ferozepur	Ferozepur Cantt.-Zira ..	10	Good.
Lahore .	Raiwind-Manga ..	11 30	
Amritsar ..	Amritsar-Chowgaon ..	9	
Gurdaspur	Batala-Qadian ..	2	
Gujranwala	Naushera-Verka-Gujranwala	18	Bad. Soil suitable but road neglected.
Gujrat .	Kunjah-Phalia ..	25	
Attock .	Gondal-Hazro ..	8	Good.
Mianwali	Paikhel-Moch ..	4·5	
Lyallpur ..	Aminpur-Narwala ..	6·7	Poor. Soil unsuitable
Jhang ..	Jhang-Rivaz Bridge ..	7·5	
Muzaffargarh ..	Muzaffargarh-Rangpur	12	Good.
Dera Ghazi Khan	Jampur-Dajal ..	15	
	Total ..	195 41	

APPENDIX No. V.

Improvement of class II unmetalled Roads in the Punjab.

Serial No.	District	Total mileage	Miles already improved	Balance to be improved	Miles Surveyed: White up to 30 % Sand	Miles Surveyed: Blue 30 to 40 % Sand	Miles Surveyed: Red 40 to 100 % Sand	Miles Surveyed: Yellow Salt Petre	Miles Surveyed: Total	Miles Surveyed: Cost per mile		Miles improved	Balance mileage to be: Surveyed	Balance mileage to be: Improved	Remarks.
1	2	3	4	5	6	7	8	9	10	11		13	14	15	16
										Rs.					
1	Hissar	439		439	98 26	9 12	24 12	5	132	627		110	307	329	T
2	Rohtak	175	14	161	51 37	15 94	22 07	9 12	98 5	675			76 5	161	
3	Gurgaon	251		251	20 28	21 62	32 10	2	76	634		12	175	239	
4	Karnal	323	2	321	91 76	6 25	99	5 5	104 5	565		48	218·5	273	T
5	Ambala	179	10	169	109	35 8	24 2		169	649	1	50	.	119	T
6	Simla ..	.	.		.	..	.		.	.		.	.	..	
7	Kangra	327	..	327			.	.	.	.		.	..	327	
8	Hoshiarpur .	243	11	232	158 10	13·08	58 42	4·41	234 01	713	1,	13	8·99	219	
9	Jullundur .	108 5	7	101 5		.	..		..	.		.	108·5	101·5	T
10	Ludhiana ..	49	12	37	14 32	1 5	6 68	2 62	25·12	837		.	23·88	37	
11	Ferozepur ..	208	10	198	29·86	7 66	36 23	20	93·70	587		50	114 3	148	T.
12	Lahore ..	250	10	240	38 73	17·79	18 12	6·38	81	373		5	169	235	T.
13	Amritsar ..	122	10	112	110 41	3 60	7 99	.	122	213		34		78	T (ordered)
14	Gurdaspur ..	198		198	41·36	27 93	22 96	..	92·25	368		80	105 75	118	T (ordered)
15	Sialkote ..	322 5	116	206 5	18	..	..	.	18	872		.	304·5	206 5	
16	Gujranwala ..	284	16	268	50 43	3	4 83	1 24	59 5	512		..	224 5	268	
17	Sheikhupura ..	287 5	.	287 5	39 25	155 11	22·64	7·5	224·5	370		145	63	142·5	T.
18	Gujrat ..	297	25	272	69 53	3 49	6 73	25	80	372		81	217	191	T.
19	Shahpur ..	390	100	290	66 40	5 99	6·99	10 62	90	396		..	300	290	
20	Jhelum ..	265 5	20	245 5	79 26	3 87	4 87	11	99	603		..	166·5	245 5	

APPENDIX IV.

Demonstration earth roads in the Punjab.

District.	Name of Road.	Mileage	Present condition.
Hissar	(1) Hansi-Sissai	4	
	(2) Hansi-Bhiwani	6	
Rohtak	Sonepat-Gohana	10	Good.
Gurgaon	Ballabgarh-Chhainsa	12	
Karnal	Karnal-Hansi	2	
Ambala	Ambala-Naggal	10	Very poor, soil unsuitable.
Hoshiarpur	Jadla-Balachaur	5 26	
Jullundur	Nawanshahr-Jadla	7 15	
Ludhiana	Ludhiana—Raikot	10	
Ferozepur	Ferozepur Cantt.-Zira	10	Good.
Lahore	Raiwind-Manga	11 30	
Amritsar	Amritsar-Chowgaon	9	
Gurdaspur	Batala-Qadian	2	
Gujranwala	Naushera-Verka-Gujranwala	18	Bad Soil suitable but road neglected.
Gujrat	Kunjah-Phalia	25	
Attock	Gondal-Hazro	8	Good.
Mianwali	Paikhel-Moch	4·5	
Lyallpur	Aminpur-Narwala	6 7	Poor. Soil unsuitable
Jhang	Jhang-Rivaz Bridge	7·5	
Muzaffargarh	Muzaffargarh-Rangpur	12	Good.
Dera Ghazi Khan	Jampur-Dajal	15	
	Total	195·41	

APPENDIX No. V.

Improvement of class II unmetalled Roads in the Punjab

Serial No.	District.	Total mileage	Miles already improved	Balance to be improved	Miles Surveyed							Miles improved	Balance mileage to be		Remarks
					White up to 30 % Sand	Blue 30 to 40 % Sand	Red 40 to 100 % Sand	Yellow Salt Petre	Total	Cost per mile	Total Cost		Surveyed	Improved.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
										Rs.	Rs				
1	Hissar ..	439		439	98 26	9 12	24·12	5	132	527	69,614	110	307	329	T.
2	Rohtak ..	175	14	161	51 37	15 94	22 07	9 12	98 5	675	66,538		76 5	161	
3	Gurgaon ..	251		251	20 28	21 62	32 10	2	76	634	48,164	12	175	239	
4	Karnal ..	323	2	321	91 76	6 25	·99	5 5	104·5	505	59,032	48	218·5	273	T.
5	Ambala ..	179	10	169	109	35·8	24 2	.	169	649	1,09,772	50	.	119	T
6	Simla ..	.				..	.	.	..			.		..	
7	Kangra ..	327	..	327	.	.		.	..	.	..	..	.	327	
8	Hoshiarpur ..	243	11	232	158 10	13 08	58 42	4·41	234·01	713	1,66,905	13	8·99	219	
9	Jullundur ..	108 5	7	101 5		.	..					..	108 5	101·5	T.
10	Ludhiana ..	49	12	37	14 32	1 5	6 68	2·62	25 12	837	21,020	.	23·88	37	
11	Ferozepur ..	208	10	198	29·86	7 66	36 23	20	93 70	587	55,000	50	114 3	148	T.
12	Lahore ..	250	10	240	38 73	17·79	18 12	6·38	81	373	30,285	5	169	235	T.
13	Amritsar ..	122	10	112	110 41	3 60	7 99	..	122	213	25,990	34		78	T (ordered)
14	Gurdaspur ..	198	..	198	41·36	27 93	22 96		92·25	368	33,996	80	105 75	118	T (ordered)
15	Sialkote ..	322 5	116	206·5	18	..	.	..	18	872	16,689	..	304·5	206·5	
16	Gujranwala ..	284	16	268	50·43	3	4 83	1 24	59 5	512	30,482	.	224 5	268	
17	Sheikhupura ..	287 5	..	287·5	39 25	155 11	22 64	7·5	224·5	370	82,999	145	63	142·5	T.
18	Gujrat ..	297	25	272	69 53	3 49	6·73	·25	80	372	29,615	81	217	191	T.
19	Shahpur ..	390	100	290	66 40	5 99	6·99	10 62	90	390	35,631	..	300	290	
	Jhelum ..	265 5	20	245 5	79 26	3 87	4 87	11	99	603	59,707	..	166 5	245·5	

APPENDIX No. V—*concld.*

Improvement of class II unmetalled Roads in the Punjab.

Serial No.	District.	Total mileage.	Miles already improved.	Balance to be improved	Miles Surveyed.							Miles improved	Balance mileage to be		Remarks.
					White up to 30 % Sand.	Blue 30 to 40 % Sand.	Red 40 to 100 % Sand.	Yellow Salt Peter.	Total.	Cost per mile.	Total Cost.		Survey-ed	Improv-ed.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
21	Rawalpindi ..	274		274	84 63		1 5	1 87	88	366	32,106	..	186	274	T.
22	Attock .	285	60	225	45 75		25		46	389	17,866	12	239	213	
23	Mianwali .	82	4 5	77 5	..	.	.			..	.	..	82	77 5	
24	Montgomery .	362		362	34 34	21 26	14·92	13 49	84	437	36,732	..	278	362	T.
25	Lyallpur .	203	6 6	196 4	135 86	22 58	19 26		177 7	328	58,252	113 4	25·3	83	T.
26	Jhang .	296 5	59 5	237	155 15	25 70	56 65	3	240 5	825	198,231	56 5	56	180 5	T.
27	Multan ..	364	30	334	45 52	15 87	8·49	0 62	70 5	233	18,510	.	284 5	334	T.
28	Muzaffargarh ..	374	13	361	57 37	13 13	10	7 50	88	494	43,423	77	286	284	
29	D. G. Khan	50	43	7	..	..	..	..	..	..	..	..	50	7	
	Total ..	7,009 5	579 6	6,429 9	1,644 94	430 28	411 01	116·55	2,602 78	517	13,45,655	886 9	4,069 72	5,643	15

Miles improved (Col. 4 and Col 13) . =1,466 5

Miles in hand and to be completed by March 1930. = 880 5

Total .. =2,347·0

NOTE.—Col. 4 shows mileage of roads improved by old method.

Col. 13 shows mileage of roads improved by modern method.

T. Tractor and Grader actually purchased.

APPENDIX No. VI.

MECHANICAL TRANSPORTATION

Estimated cost of transportation by a kerosine oil tractor and two 5-ton trailers to Mandis.

Plant to travel six to eight miles an hour and haul a load of 10-ton.

Capital expenditure.

			Rs.
1. Tractor at Rs. 4,500/-		..	4,500
2. Trailers at Rs 2,000/-		..	4,000
			8,500
I. 5% interest		..	425 per annum.

II. Depreciation.

Life of tractor 4000 hours or	1·12 per hour		
trailers 8,000 hours or	·5		
	1·62	..	1·62

III. Running costs (excluding I and II).

Running cost for 4,004 hours Rs. 9,466/- (actual experience, see details)—		
Cost per hour	..	2·36
Total running cost per hour	..	3·98
say Rs.	..	4 per hour.

. **Annual cost of establishment.**

		Rs.
Driver's pay Rs. 100/- p.m.	..	1,200
Attendants pay Rs. 50/- p m.	..	600
		1,800

Total annual cost (assuming plant works 800 hours or 100 days).

(*a*) Establishment	..	1,800
(*b*) Interest	..	425
(*c*) Running costs 800 × 4	..	3,200
(*d*) Repairs	..	500
		5,925
say Rs.		6,000

APPENDIX No. V—*concld.*

Improvement of class II unmetalled Roads in the Punjab.

Serial No.	District	Total mileage	Miles already improved	Balance to be improved	Miles Surveyed. White up to 30 % Sand	Blue 30 to 40 % Sand.	Red 40 to 100 % Sand.	Yellow Salt Peter	Total	Cost per mile.	Total Cost.	Miles improved	Balance mileage to be Surveyed	Balance mileage to be Improved	Remarks.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
21	Rawalpindi .	274		274	84·63		1·5	1·87	88	366	32,196		186	274	T.
22	Attock	285	60	225	45·75		25		46	389	17,866	12	239	213	
23	Mianwali	82	4·5	77·5									82	77·5	
24	Montgomery	362		362	34·34	21·25	14·92	13·49	84	437	36,732		278	362	T.
25	Lyallpur .	203	6·6	196·4	135·86	22·58	19·26		177·7	328	58,252	113·4	25·3	83	T.
26	Jhang	296·5	59·5	237	155·15	25·70	56·65	3	240·5	825	198,231	56·5	56	180·5	T.
27	Multan ..	364	30	334	45·52	15·87	8·49	9·62	79·5	233	18,516	.	284·5	334	T.
28	Muzaffargarh ..	374	13	361	57·37	13·13	10	7·50	88	494	43,423	77	286	284	
29	D. G. Khan .	50	43	7	.	..	..		..	.	.		50	7	
	Total ..	7,009·5	579·6	6,429·9	1,644·94	430·28	411·01	116·55	2,602·78	517	13,45,655	886·9	4,069·72	5,543	15

Miles improved (Col. 4 and Col. 13) .. = 1,466·5

Miles in hand and to be completed by March 1930. = 880·5

Total .. = 2,347·0

Note.— Col. 4 shows mileage of roads improved by old method

Col. 13 shows mileage of roads improved by modern method

T. Tractor and Grader actually purchased

III.—Relation between power required for transportation and ploughing per unit area.

Assume working period for ploughing as 100 days during the year and lead for transportation as 12½ miles.

On an average one tractor can plough about six acres per day or 600 acres a year (of 100 days). Taking yield of agricultural produce as [illegible] produce would figure out [illegible] ortation outfit could make [illegible] erefore the outfit could [illegible] 1/11th the time required for ploughing this area.

If the lead were increased to 25 miles the tractor could be used for transportation for 18 days. It will thus be seen the power required for ploughing is far greater than required for transportation per unit of area.

DISCUSSION

Mr. Nand Gopal, remarked as follows :—

The author of the paper has dealt with Provincial, District and Village Roads as the only possibilities for use of Grading Machinery. The speaker thought that its scope could be very usefully and economically extended to Canal Roads as well and more particularly to Roads along Drains. It is true that these roads are not generally open to Public but of late years a policy has been adopted to open these to the public without permits as far as possible. The figures for maintenance of roads given by the author are so low that a canal Engineer can look forward to much use of this machinery, for both classes of his roads—those open to Public and those reserved for Departmental use. The author works out the cost of maintenance of his roads at Rs. 70 p.m., per annum, taking a traffic load of about 100 bullock carts and 15 Motor Vehicles, per day. Canal Roads have a much lighter traffic than this. For Public roads for Maintenance he finds gradings five times a year necessary. For canal Roads twice a year would perhaps be enough, one soon after the Monsoon, say in October, and the second after the winter rains, say in February. This will reduce the cost to two-fifths, say about Rs. 28 only per mile per annum. Again canal roads are generally in much better condition to begin with and the number of times the grader will have to run for each grading will probably be only one, against three for public roads.

This will further reduce the cost to only about Rs. 10 per mile per annum. This is very reasonable figure, which can be easily met from the ordinary Annual Maintenance and Repairs estimates. These remarks apply more particularly to what are termed "Boundary roads" for maintenance of which at present very little is available from the usual allowances for Maintenance and Repairs of Canals and Distributaries. It will thus be possible to open more of them to the Public. Roads on banks are reserved for departmental touring officers and on boundary roads only restricted traffic is possible, owing to the high cost of maintaining them in reasonable order if no restrictions were in force. The use of graders would certainly reduce these costs. It would be advisable for the author to extend his help, to begin with by giving demonstrations in some Canal Divisions. It can not be said yet whether the Canal Department will be prepared to buy a few sets of Machinery for trial. This will depend largely on whether enough work can be found for each set within the time a certain area has to be served.

The author's figures of cost are based on a very moderate estimate of 100 working days per year, during which according to him about 1300 miles can be covered.

For canal roads requiring two gradings a year, 100 days could not be extended over the whole year, but it would be necessary to concentrate work during October, November, February and March. The machines would thus be expected to run continuously during these four months.

could combine to have one, or if only a limited use were permissible, one Canal Circle could keep one set. It is time that canal Engineers turned their attention to this method of maintaining their roads and took advantage of the most excellent lead given by the author and all the useful data collected by him in his paper.

Bawa Budh Singh remarked as follows :—

Earth roads if properly drained and maintained can serve the rural areas for all their needs, provided the soil is good. The GRADER dresses up the road surface well by cutting the ridges and filling up the valleys, but the filling is always softer than the newly cut surface. It would greatly improve the surface, if a fairly heavy roller followed the Grader, and rolled down the freshly dressed surface. Continuous use of the Grader is likely to lower the road formation below flood level. A submerged earth road is a great nuisance to traffic, therefore, efforts should be made to keep important katcha roads dry throughout the year.

The intensity of Motor vehicle traffic on Punjab roads is not one half of that in Western countries. The construction of very expensive roads cannot be warranted on the score of traffic alone.

The Communication Board's classification of roads, appears to be arbitrary. Some of the artérial roads **viz**; Dera Ghazi Khan—Mithankot and Muzaffargarh—Alipur roads do not satisfy the definition of an Arterial road, as given on page 111.

The speaker would suggest that the improvement or reconstruction [illegible] Government contributes more [illegible] ried out by Government, rather [illegible] District Boards.

Mechanical Transport.

The author of the paper has stated that improvement of the roads will lead to the introduction of more motor vehicles in the country.

He has written in another place that the great obstacle to more extended use of Motor Vehicles for the transportation of goods, is the deplorable state of village roads. Unless the latter are improved, very little progress in this direction can be expected

Again he advises lorry owners to literally force their way into villages by ½ ton and ¾ ton buses and start passenger services. This penetration will ultimately pave the way for goods lorries. No one can deny the importance of the subject to this country. The author has not only [illegible] s also expressed [illegible] f *the Civil and* [illegible] icity, one might

coms to the conclusion, that the proposed improvement of our roads is to lead to an introduction of Mechanical Transport into the country on large scale.

The object of the author is laudable, it is to awaken India by Motor Transport, and the subject deserves very serious consideration at the hands of this Congress and Indian economists

The author estimates the cost of properly maintaining and improving [illegible]

what the Government spends at present on roads Hence the amount spent on improvement will be recouped by income from taxes, etc. The argument is correct so far as Government is concerned; but what about the enormous capital required to purchase the Motor Vehciles? Supposing a vehicle costs Rs 3,000 on the average, the total capital investment would be Rs 111 crores

The annual drain of money from the country would roughly be another 45 crores .—

		Rupees.
(1)	Interest on Capital @ 9 per cent per annum ..	10 Crores.
(2)	Cost of spare parts, tyres etc., @ 200 per vehicle ..	7.4 Crores.
(3)	[illegible]	27.75 „
	Total Rupees ..	45 Crores.

Can India afford all this Capital investment as well as the annual expenditure, with her meagre resources?

[illegible] Transport and other [illegible] /e are the producers [illegible] ot need complicated machinery for their export Let a thorough investigation of the ways and means for the development of India's industries precede the wholesale introduction of Mechanical Transport into the country.

[illegible] -ulture and the [illegible] In this con- [illegible] would remark that the province is a land of small holdings and the agricultural unit of the farmer is *a plough* or a pair of bullocks. These bullocks are his economic unit which do his ploughing sowing, water lifting, harvesting and cartage of his crops to the market. They are fully employed throughout the year with a rest in the rainy season. The principal agricultural implements are: the plough, the persian wheel and the bullock cart,

simple in construction, and maintenance, prepared by the village carpenter with the timber available from the trees in the fields. No doubt the mechanical efficiency of these primitive implements is not as great as that of up-to-date machinery; but the fact that they can be worked by bullock power, makes the zamindar cling to them.

The case of big landholder is different, and the problem is quite different from that on the ranches of Canada and Australia, where thou- [illegible] absorb them. Unemployment will increase, and with it unrest.

Moreover, Farm Machinery has still to prove its fitness and economy in this land of small holdings.

[illegible] cat T [illegible] work [illegible] a bullock-cart.

He calculates the cost per ton-mile by Tractor Trailor transport at four annas against eight annas by bullock cart, but these figures cannot be accepted at their face values. The cost per ton-mile by Mechanical Transport is pitched too low, while that for the country cart is too high. [illegible] Motor [illegible] on one [illegible] per ton-mile. The bullock cart generally travels empty homeward. It is unlikely that a ten-ton tractor trailor-unit would find a sufficient number of passengers or goods for the return journey to the village—a village not being an industrial centre.

The author has omitted to give details of his 0-8-0 per ton-mile cost by bullock cart.

[illegible] has taken the figure of 800 hours. Interest has been placed too low, no agriculturist can raise a loan @ 5 per cent interest, the rate of interest would be nearer 10 per cent than 5 per cent. Repairs, spare parts, and tyres etc., would certainly cost more than 500 per annum, as the tractors and trailors in rural areas will not work under the supervising eye of an engineer and his establishment, as in the case of experimental working.

The cost of loading and unloading goods in a ten-ton unit would be considerable and would add to the cost of the trailor transport. In

addition there is the damage wrought by such heavy mechanical transport to the roads, and it becomes evident that a tractor cost much more than four annas per ton-mile

Until the country developes its industries to a higher level the introduction of Mechanical Transport will prove ruinous both to the villagers and to the roads.

In conclusion, the author's admission, on page 122, to the effect, that there is no vehicle in existence or projected throughout the world which would carry goods in large quantities at low cost on earth roads without unduly damaging them is disappointing, and it would appear that he has not made out a case for the introduction of Mechanical Transport on earth roads in the Province

Mr. K. B. Kewalramani noticed that the author on the first page of his paper found it very difficult to understand how a comparativeley poor country like India could afford to maintain about 28 per cent of her total mileage of roads as surfaced when a rich country like U. S. A. could only afford to surface only about 20 per cent of its roads

From Appendix I Belgium has surfaced cent per cent. of her total road mileage against 20 per cent in America. Is it therefore to be concluded that Belgium is richer than America? The fallacy lies in not calculating road mileage on basis of population or total area of each country.

If the author works out the total road mileage in India and compares the same with that of other countries per million square miles of area or per million of population in each country he will find no difficulty in understanding what he says he cannot understand now. The following table is illustrative —

Country	Area in million square miles	Population in millions	*Road miles (thousand miles).*			*Total Road mileage in thousands*	
			Earth or gravel	Surfaced	Total	Per million sq miles.	Per million of population.
U. S. A ..	3 7	117	2400	600	3000	810	25
Japan ..	·26	77	72 7	1	72 8	280	·95
Belgium .	·01	7 7	..	6 3	6 3	630	·82
France ..	·21	39	415 4	24 6	440	2095	11·3
Germany ..	·25	61	102 6	25 6	128 2	513	2 1
Italy ..	·12	37	27 2	86 4	113 6	947	3 0
India ..	1·7	300	150 7	60 3	211	124	·7

So with 20 per cent. U.S A. has surfaced about 162 thousands miles per million square miles area; whereas in India 28 per cent of total mileage works out to only 34 7 thousands per million square miles, which is comparatively much easier to surface.

simple in construction, and maintenance, prepared by the village carpenter with the timber available from the trees in the fields. No doubt [illegible] ot as great as [illegible] worked by [illegible]

The case of big landholder is different, and the problem is quite different from that on the ranches of Canada and Australia, where thou- [illegible] There, [illegible] of [illegible] in [illegible] to absorb them Unemployment will increase, and with it unrest.

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He calculates the cost per ton-mile by Tractor Trailor transport at four annas against eight annas by bullock cart ; but these figures cannot be accepted at their face values. The cost per ton-mile by Mechanical Transport is pitched too low, while that for the country cart is too high. Referring to the author's article in the *Civil* and *Military Gazette,* 'Motor Transport in the Punjab', he says " If a full load is obtained on one journey only, this would figure out at annas eight to annas ten per ton-mile " The Bullock cart generally travels empty homeward. It is unlikely that a ten-ton tractor trailor-unit would find a sufficient number of passengers or goods for the return journey to the village—a village not being an industrial centre.

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addition there is the damage wrought by such heavy mechanical transport to the roads, and it becomes evident that a tractor cost much more than four annas per ton-mile.

Until the country developes its industries to a higher level the introduction of Mechanical Transport will prove ruinous both to the villagers and to the roads

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India ..	1 7	300	150 7	60 3	211	124	·7

So with 20 per cent. U.S. A. has surfaced about 162 thousands miles per million square miles area; whereas in India 28 per cent of total mileage works out to only 34·7 thousands per million square miles, which is comparatively much easier to surface.

Mr. K. G. Mitchell remarked that, as stated by Mr. Stubbs, they had in the Communications Board, been emphasising the importance of earth roads since 1921 but that it has taken till 1927 to get things going He was however glad to say that people were taking interest in the subject now. He remembered that in 1922, the Communications Board offered to pay the cost of improvir [illegible] earth road which any Assistant E [illegible] up as a hobby but as far as [illegible] ually they started demonstration roads of about ten miles in twenty districts to show what could be done and what the cost would be. Mr. Stubbs had pointed out that in three cases these demonstration roads were failures and stated that they were expensive as they were built by manual labour. They were of course expensive as it would not have done to risk failure by leaving them too low in districts liable to heavy rains or flooded roads from Abzaya but they had been of great value for their object, as the subsequent history proved The failure of the Gujranwala District Board to maintain what had been made into an excellent road was however ominous

Referring to the statement at page 119 he felt that so many roads were badly depressed that the provision for extraneous filling was inadequate.

He noted that on page 110 at the bottom Mr. Stubbs expressed the pious hope that the revenue obtained by the Government of India from the import and excise duties on motor spirit and from various other taxes would all be eventually ear-marked for road development. He was doubtful about this and the argument developed therefrom by Mr Stubbs that the only way to finance roads was to increase without limit the motor traffic using th m H pointed out that at the present moment the two anna surcharge on petrol, which is all the roads can look to, brings in only about seven per cent of the total road bill of India.

As to the use of graders in the Punjab referred to by Mr. Stubbs on page 114, he said that it was not found possible to use the western grader by hiring bullocks which were not often available when wanted. This machine was of course primarily one for maintenance work. As regards the rural grader, Hercules ractor for the purchase of which he was responsible, the tractor had been selected with the aid of the Indian Stores Department and in consultation with the makers.

He considered that some of the figures in the Appendices were misleading. For instance, according to Mr. Stubbs Mexico had 37 motor vehicles per mile of road while Great Britain and the U.S A. had only eight or ten.

As to Bawa Budh Singh's remarks that it will greatly improve the surface if a fairly heavy roller follows the grader on the freshly dressed surface, he said that the difficulty was that the soil was often so dry that grading produced fine dust or powder which, it was no use rolling until

it had had a fall of rain or some canal water. He hoped that eventually with the co-operation of the Irrigation Branch arrangements could be made for regular watering which was very desirable for maintaining earth roads in good order.

Mr. G. T. Pound said that the fact must be faced that this Province could not or would not find the money to maintain the roads [illegible] to the number [illegible] be built and [illegible] led until the traffic on it became so heavy that it was impossible or uneconomical to maintain it as an earth road.

He had nothing to say against the use of graders and tractors for road construction provided the programme was large enough to keep them fully employed Smaller programmes could be carried out by manual labour. This did not involve the digging of borrow pits as Mr. Stubbs seemed to suppose He had cambered and graded an earth road by manual labour at a cost of about Rs 200 per mile.

For maintenance he advocated the use of drags which could be made locally and pulled by bullocks The use of a number of drags enabled a long length of road to be smoothed when the surface was drying up after rain. A maintainer with a hundred miles to cover would not be able to do this.

In places where gravel was available he suggested that on sections where a metalled width of twelve feet was not sufficient, gravel shoulders would be found cheaper than widening the metalled surface both in construction and maintenance.

[illegible] referred to the statement made at the [illegible] nts had been tried for [illegible] and turning traffic on [illegible] up.

Thirdly, he asked if any instance had occurred of an earth road which had reached " saturation point " on which the traffic had become excessive and if so what procedure had been then adopted.

Mr. Nicholson described his experiences when recently on tour to Jhang, Multan and Muzaffargarh Districts. He found that some of the finest roads he came across during his tour were cut up by water-course crossings, and he considered that arrangements should be made for the provision of culverts at such sites.

As regards grading, it was clear that at times the roads could not be properly rolled and maintained owing to lack of water. He suggested that

if the District Board or the Communication Board were unable to arrange for this, they should refer the question to the Irrigation Branch who would be in a position to make the necessary arrangements.

Mr. Dhodhy referred to a small machine known as Martin Ditcher which was used by him about 10 years ago. He said it could be used by a pair of bullocks. It cut off earth at its outer end and piled it in the middle. This could then be rolled over. It cost, then, about Rs. 400 and he thought it quite useful for improving canal bank or boundary roads.

Mr. Stubbs, in reply to points raised in the discussion, said he was unable to reply really satisfactorily offhand. He was pleased to hear a suggestion emanating from a canal officer that road graders should be used for canal boundary roads which should be thrown open to the public as this would mean bringing thousands of miles into beneficial use, and would be a great asset to the Province.

[illegible] extensive use [illegible] h roads was a [illegible] an opinion— time alone would show whether he was right. He was certain India [illegible] extensive use that was made of earth roads in various parts of the world as compared with India.

He agreed with Mr. Pound that the use of gravel on the berms of metalled roads would be beneficial. He explained to Mr. Mitchell that the steam Hercules tractor was designed to exert its maximum draw bar pull at a speed far in excess of two miles an hour, the average speed at which road grading is carried out. For this reason this tractor was not up to the job of road grading.

He told Mr. Trevor Jones that observations show that under average soil and traffic conditions the carrying capacity of an earth road was 100 bullock-carts and about 15 motor vehicles daily, when this limit was reached a gravel road was necessary.

PAPER No. 138.

HYDRAULIC GRADIENTS IN SUBSOIL WATER FLOW IN RELATION TO STABILITY OF STRUCTURES RESTING ON SATURATED SOILS.

By Ajudhia Nath Khosla, B A, I S E, Executive Engineer, A M I E, (India).

Introduction.

The author has had to face, during the last three and a half years, serious trouble in connection with the upstream and downstream floor of some of the drainage siphons on the Main Line of the Upper Chenab Canal, more specially th. Dugri No. 1 and Jauryan siphons.

Dugri 1 Siphon.

The trouble on the Dugri No 1 (R D 35,800) siphon downstream, however, occurred as early as 1915 when high supplies were run in the canal for the first time Springs appeared beyond the drop wall. In 1917 the floor was extended and strengthened. In 1919 the right wing

bays for draining water at a lower level. Relief pipes were inserted in the floor In 1921 the springs became extremely active blowing out sand freely. The right wing wall settled out of plumb. The trouble finally extended to the face wall which cracked due to the settlement of the barrel lips. The barrels cracked inside. In 1923 a line of sheet piles 20 feet deep below bed (see plate VI) was put in 7'0 feet away

This proved equally ineffective. A proposal was put up of puddling the canal bed and side slopes for a length of 100 feet upstream and downstream of the siphon to kill the hydraulic head under the floor. This however was never carried out.

floor was further strengthened and repaired.

if the District Board or the Communication Board were unable to arrange for this, they should refer the question to the Irrigation Branch who would be in a position to make the necessary arrangements.

Mr. Dhodhy referred to a small machine known as Martin Ditcher which was used by him about 10 years ago. He said it could be used by a pair of bullocks. It cut off earth at its outer end and piled it in the middle. This could then be rolled over. It cost, then, about Rs. 400 and he thought it quite useful for improving canal bank or boundary roads.

Mr. Stubbs, in reply to points raised in the discussion, said he was unable to reply really satisfactorily offhand. He was pleased to hear a suggestion emanating from a canal officer that road graders should be used for canal boundary roads which should be thrown open to the public as this would mean bringing thousands of miles into beneficial use, and would be a great asset to the Province.

In reply to Bawa Budh Singh he said that the far more extensive use of motor vehicles when the country was opened up by earth roads was a prophecy and that motor transport would awaken India was an opinion—time alone would show whether he was right He was certain India would not be ruined by introducing mechanical transport. The very great accuracy or otherwise of road mileage, etc. of various countries was of academic interest only as these figures were merely used to show the very extensive use that was made of earth roads in various parts of the world as compared with India.

He agreed with Mr. Pound that the use of gravel on the berms of metalled roads would be beneficial. He explained to Mr. Mitchell that the steam Hercules tractor was designed to exert its maximum draw bar pull at a speed far in excess of two miles an hour, the average speed at which road grading is carried out For this reason this tractor was not up to the job of road grading.

He told Mr. Trevor Jones that observations show that under average soil and traffic conditions the carrying capacity of an earth road was 100 bullock-carts and about 15 motor vehicles daily, when this limit was reached a gravel road was necessary.

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HYDRAULIC GRADIENTS IN SUBSOIL WATER FLOW IN RELATION TO STABILITY OF STRUCTURES RESTING ON SATURATED SOILS.

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Introduction.

The author has had to face, during the last three and a half years, serious trouble in connection with the upstream and downstream floor of some of the drainage siphons on the Main Line of the Upper Chenab Canal, more specially the Dugri No. 1 and Jauryan siphons.

Dugri 1 Siphon.

The trouble on the Dugri No. 1 (R. D. 35,800) siphon downstream, howe [illegible] were run in the canal [illegible] e drop wall. In 1917 the floor was extended and strengthened. In 1919 the right wing [illegible]

bays for draining water at a lower level. Relief pipes were inserted in the floor. In 1921 the springs became extremely active blowing out sand freely. The right wing wall settled out of plumb. The trouble [illegible]

This proved equally ineffective. A proposal was put up of puddling the canal bed and side slopes for a length of 100 feet upstream and downstream of the siphon to kill the hydraulic head under the floor. This however was never carried out.

In the meantime trouble had extended to the [illegible]

were also remodelled and founded on wooden piles and the downstream floor was further strengthened and repaired.

All these however proved ineffective as springs continued to blow out sand at the end of the floors both upstream and downstream. Settlement cracks started appearing and finally the situation became as dangerous in 1928 as ever it was before.

All the repairs and extensions mentioned above were based on a hydraulic gradient of 1 : 10 taking no account of the high spring level all round the work both upstream and downstream.

This was based on the Hydraulic Gradient Theory as set forth by **Mr. Bligh** in Chapter VI of his book. The object of this paper is to show, how **very materially** this theory can be **at variance with facts.**

Jauryan Siphon.

The author took charge of the Marala Division in April 1926 The Jauryan siphon (R. D. 63,800) had been giving cause for anxiety for over [illegible] ve just outside the pacca floor. [illegible] the wing walls and the face [illegible] The siphon was saved from further damage by heading up supply on top of the floors by putting up bunds upstream and downstream so that there was no chance of sand blowing out. A number of proposals were under consideration at the time for rendering the structure safe. One of these was to line the bed and slopes 125 feet upstream and 125 feet downstream of centre line of [illegible]

width of stone pitching. This work was executed in the January closure of 1927. The upstream floor, wings and face walls were also rebuilt. [illegible] study [illegible] above [illegible] adient.

The results of pressure pipes observations soon disclosed that whereas **the puddle was absolutely watertight it was absolutely ineffective in reducing the upward pressures** under the floor which were **governed by the subsoil level** (not the level of the flowing water in the cunette or drain) **in the vicinity of the work.** The puddle cut off the local percolation but this was going on above and below this length thus keeping the subsoil water level unaltered even in front of the puddled length. The history of these two siphons clearly demonstrates how **works originally safe can become unsafe with a rise in the spring level.**

The upstream and downstream floors of the Jaurian siphon were remodelled in May 1927 on the basis of the latest information about pressures under floors of this nature. The trouble however did not end Six mo[illegible] iddle walls, both [illegible] ed at the end of [illegible] end

and clay. The cracks being far away from the face of the barrels, there was no immediate danger, but the design was by no means the last word. After careful study of the local conditions it was believed that **the fault lay with the shallow end curtain walls,** only $2\frac{1}{2}$ below top of floor which permitted sand blowing under pressure. Subsequent study, which forms the bulk of the paper, confirmed this belief.

After the summer of 1928 benefitting from the mistakes of the earlier designs, the remodelling of the Dugri floor which had become dangerous by them, was designed on the lines of the Jaurian siphon, so far as upward pressures under the floors were concerned with a line of sheet piles 8 feet deep at the ends as a drop wall to prevent sand blowing out from underneath The deep sheet piles were objected to in view of the fear of "piling up" of pressure behind them and underneath the pacca floor

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was executed in January 1929 and the experimental work carried out so far shows that the design is sound It is now proposed to add a line of sheet piles each to the Jauryan floors to make them safe.

The Origin of Experimental Work.

The above narrative of the troubles at the siphons, the various remedial measures employed and of the results achieved, brings out in

the conclusions derived, therefrom, are described in the pages that follow. Some of these conclusions differ very materially from accepted theory and established practice and as the principles involved are of wide practical application, being of vital importance, the author has ventured to present these to the Congress in the hope of inviting criticism and thus deriving benefit from the experience of other engineers.

From Colonel Clibborn's experiments of 1896 at Roorkee, on the Passage of Water Through Sand and from the discussions on these printed in G. of I. Technical paper No. 97 of 1902 as also from record of observations at the Narora Weir, the Upper Chenab Canal siphons and other places, it may be safely concluded that :—

(1) As in pipe line flow, so in subsoil water flow, the
Pressure Gradient is represented as nearly as possib

joining the upstream and downstream free water surfaces provided that the medium is uniform and that there are no obstructions of any sort in the region of flow.

In figure 1, Plate 1, AB represents the Hydraulic Gradient line for the pipe PP when A_1 and B are free surfaces at either end, A_1 A being loss of head at entry. The water level in a stand pipe, inserted at point X, will rise up to the point Y where the vertical through X will cut the H. G. line.

The above sketch exactly represents the [illegible]

through subsoil. There is, however a very important factor involved, which has so far always been ignored in subsoil water flow and it is believed that it is being put forward for the first time in the paper. In the case of free water moving through a pipe line, BB. represents the true water level at exit as it is assumed that there is no velocity head in the reservoir BB. If the pipe were discharging free with a velocity of exit at P_1 the head due to that velocity of exit will have to be plotted as BP to get the true free water surface for purposes of obtaining the true H. G. line.

In figure 2, Plate I, A_1 A is the free water surface upstream and B_1 B_1 the **apparent** free water surface downstream. A_1 P_1 is a vertical wall and P P_1 an impervious floor formed on sand or other soil. Beyond P_1 the foundation soil is exposed. According to the commonly accepted theory A B_1 will represent the H. G. line. This will be so only if the flow at the level B_1 B_1 has no velocity or in other words there is no flow. But if the subsoil water coming out of the exposed surface of soil P_1 P_2 has a velocity, the head equivalent to that must be added above B_1 B_1 to get the true free water surface BB The line joining A B will then be the true H. G. line. This phenomenon of the **true free water surface** being very much **higher than the apparent free water surface** is clearly demonstrated by the experimental work at the siphons and by the analysis of the available data of weirs. This will be fully discussed later on but it may be mentioned [illegible]

(see photographs No. 6 Jauryan Siphon) The exact significance of this curve and of the influence of curtain walls on the H. G. Line will be explained later.

Experiments with Pressure Pipes at Dugri No. 1.

The general arrangements of these pressure pipes is shown on photographs No. 4. 5 and 6 and in plan on Plate VII. There is a row of pressure pipes fixed in the middle wall spaced about 10 feet apart. These pipes (No. 1 to 5) 1½" or 1¼" diameter, have filter points at the bottom, 2' to 2½' long. There are three 10' long Tej

strainers 5" internal diameter, one in the middle wall and one each in the wing walls. These are meant to relieve the upward pressure under the floor. Temporary pressure pipes with filter points at the bottom ends, were fixed in line with the central wall, Nos. 13 and 14 between the canal and the face wall and Nos 6 to 12 outside the pacca floor.

Pressure pipe observations had been made on the Jauryan floor for the past two years and advantage was taken of the experience gained there, in arranging the pipes in the new Dugri floors. The relief strainers added considerably to the scope of the experiments.

Object of Experiments.

The object of these experiments was to determine:—

i. The pressures under the floor under varying conditions of canal supply and spring level.

ii. The correct location of relief strainers and the extent to which these are useful in relieving strain on the floor from upward pressure or from the blowing out of foundation soil.

iii. The true free water level in the open bed as against the apparent free water level or the level of the water flowing over the cunette floor

Procedure.

[illegible]

combinations. [illegible] strainers open or all closed To begin with, these observations were taken every half hour when the canal was opening and for a few days afterwards. But as the [illegible]

The pressure pip[illegible] of two feet intervals after 48 hours and observations were recorded morning, noon and evening. Statement I gives the details of filter point levels for all pipes on different dates [illegible]

levels stepping up as on first day, (ii) intermediate stage, (iii) all well points fully down, (iv) as per (iii) with the cunette level gone up from R. L. 789 5 to 790 5 owing to a flood in the nallah. Nos. 6 and 7 were then gradually pulled up and the pressures in these fell according to the height pulled up.

Similar observations were carried out for six weeks at the Jauryan siphon with similar results

Analysis of Experimental Data.

Some of the apparently eccentric results really bring out certain important points. The plots of No 10 show a distinctly greater drop from No. 9 than those of No 9 do from No. 8 although the distance between the two sets is the same. This is due to the fact that the bed level at No. 10 is 0 7′ to 0 8′ lower than the bed levels at No 9 and No. 8 so that to get the same pressures, the well point of No. 10 has to go down about one foot deeper. This point is dealt with later on where it is shown that **scour immediately below a pacca floor may endanger an otherwise sound floor** by increasing the velocity of discharge at the end in proportion to the depth of scour and thus augmenting the tendency for "piping" or dislocation of soil particles from beneath the foundation. Some of the eccentric results of Nos 10 and 9 are due to the presence of springs close to them and also due to leakage vertically along the pipe due to the surrounding soil not having had sufficient time to get compact. These leaks when stopped at once produced normal results in the pipes. A large range of results was thus obtained covering depths below floor up to 23 feet.

To get at a general law these results (with strainers closed) were arranged so as to show the difference of head between the normal spring line joining the indicated pressure levels on pipes 2, 3 and 4 and the indicated pressure in each pipe for each depth of strainer (filter point). This method of obtaining the normal spring line called (N. S. L.) is not quite correct as the H. G. somewhat flattens out as it recedes from the end of the pacca floor and the observations in No. 11, 120 feet away from the face confirm this. This, however, was a close enough first approximation of obtaining loss of head at each depth. These results, it will be noticed, are independent of the canal level as the N. S. L. is taken from observations of the pipes 2, 3 and 4 on the same date and time.

Loss of Head Curve.

Separate curves like the one shown in plate VII were then drawn for each pipe showing the loss of head on the horizontal and depth of strainer below floor on the vertical axis.

In the curve of plate VII T R. is the normal spring level or the **True Free Water Surface** referred to in the earlier pages, that is a level to which water will rise in the subsoil due to the static head if there were no flow occurring in a vertical direction. This can be possible in two ways: (i) if the area under consideration be covered with [illegible] subsoil extends above [illegible] level line is beyond the [illegible], it were dug in the soil the subsoil water would rise up to the normal spring level. If a pipe with a length of strainer at bottom were inserted in this soil the water in this pipe would rise to the normal spring level irrespective of the depth to which the strainer has been driven. This will apply to both of the above cases. Now, suppose the soil is removed up to line LH., (bed of drain)

flow will start through the subsoil in vertical direction due to the difference in static head between the normal spring level and the water level CQ' in the drain bed LH. This loss of head or shortly called " head " which produces this vertical flow is plotted as LH. at the bed level of the drain.

Suppose a pressure pipe were inserted in the soil such that the top of the strainer portion is at level P, then the water in this pressure pipe will rise to R, or up to the spring level line if the ground level is much above this line but it will rise only to Q, if the ground level is at LH. [illegible] efore the loss of head caused [illegible] PP'. The plot of all such [illegible] e" These curves of loss of head for the various pipes closely resembled each other. After making correction for difference of bed levels from the normal bed level of 788·0 and for N. S. L. (this was very slight) the points of all these curves were reproduced on one common curve of plate VII, the observations of various pipes being given distinctive conventions. A smooth curve was run through these points and the equation of the curve was determined as explained below.

The slopes $\frac{dh}{dy}$ of the curve were measured at each 2' depth and plotted against depth " Y " to a suitable scale. These showed a marked similarity to the original curve. A second curve was plotted with " h " or loss of head on the horizontal axis and the slopes $\frac{dh}{dy}$ at that point on the vertical axis. This was a straight line giving the relation

$$h = k\frac{dh}{dy} \qquad \text{(i)}$$

Integrating we get for the equation of the original curve

$$y = k \log h - c \qquad \text{(ii)}$$

where k and c are constant whose value work out as :—

$k = 15{\cdot}5$

$c = 9{\cdot}0$

Thus giving $y - 15{\cdot}5 \log h = 9$ .. .. .. (iii)

The Loss of Head Curve, it might be noted, does not quite pass [illegible] the region of clayey loam showing that the constants [illegible] ot effect the main discussion. [illegible] contribution to the present knowledge of flow of water through subsoils as effecting stability and designs of structures.

The properties and practical applications of this important curve are examined in detail below.

Velocity of Subsoil Water Flow.

According to Darcy the velocity of water flowing in subsoil channels varies directly as the head and inversely as length and may be expressed by the equation $v = ki = \frac{kh}{y}$ where v is the velocity of the flow, k a constant (called the tr [illegible] all (h) in a given [illegible] lraulic Gradient [illegible] it is a curve as in the present case then $v = k \frac{dh}{dy}$ .. .. (iii)

but from equation (i) $h = k' \frac{dh}{dy}$

$$\therefore v = \frac{ki\,h}{k} = K\,h \text{ where } K = \text{constant.}$$

Hence the velocity of flow at any point in the subsoil is directly proportional to the loss of head from the normal S. L. at that point.

As explained below this relationship is of the utmost importance in a study of the foundations in wat r-logged soils and also in a study of the yield from tube well st ain r. This will not apply where the Hydraulic Gradient follows a straight line as the velocity in that case is constant.

The convixity of the loss of head curve indicates that the rate of loss of head $\frac{dh}{dy}$ increases as the depth below the surface decreases. Since the velocity of flow is proportional to $\frac{dh}{dy}$, $(v = k \frac{dy}{dh})$ to right

Hence velocity increases as the depth decreases.

This has two very important applications.

Critical velocity critical head and dislocation of foundation soil particles.

1. The dislocation of subsoil particles is a function of the velocity of flow of subsoil water through them, **hence the tendency for dislocation of subsoil increases as the depth below the bed decreases.** It will be nothing at infinit and maximum close to bed level. There is, however, a **critical velocity** for each type of soil particl s. If the subsoil water flows with a velocity less than this there will be no disturbance or dislocation of particles but if the velocity is above the critical the soil particles will be dislocated in proportion to the increase. This velocity of flow being highest at the surface naturally the soil dislocation starts vigorously followed by decreasing dislocation as we go lower down till where the critical velocity is reached this disclocation will stop. The depth at which this occurs may be called the **Critical Depth** and the head or the loss of head at this point from the Normal Spring Level (or the true free water surface), the **Critical Head.**

The existence of heads, much in excess of the critical, leads to degradation of bed and sides In this connection the formation of springs just outside the inverted filters of the siphon floors are noteworthy and also the fact that all these filters have settled at a slope from the pacca floor outwards, the settlement being maximum at the outer ends. This

floor will be drawn out causing **settlement** and final **collapse.**

2. T... arge through strainers ... **inflow per foot len**... **pth below ground decr**... duced from M... strainers, for ... this discussion is not carried any further except in so far as they serve as relief pipes

Looked at in another way a better conception of this flow is possible (*see* Plate II, figures 4 and 5) Imagine a vertical plane V V′ the soil on the left of it being boxed The flow at a point S towards right across the vertical plane V V′ and then to the top will be due to a head = H, less the head required to overcome frictional resistance in a length of subsoil = ' y ' Call this **Friction Head** ϕ (y) As the velocity of flow at any point is proportional to head the flow at S will be proportional to

charge.

In the above w... which the water has ... Tej or some similar ... head will be :—

$H - (h_e - \phi\ (y)$ (*See* figure 5).

Where h_e is the loss at entrance at the slits and ϕ (y) is the loss due to friction through the strainer pipe. This quantity decreases as y′ increases showing that the velocity and discharge (inflow) of the strainer decreases as the depth increases There are other factors besides the above but this is just to explain the broad issue. ϕ (y) will of course be much greater than ϕ (y) so that the loss of head or (working head) curve will give higher values for a strainer than for a sand column.

Again ϕ (y) will be very much less for strainers of the Tej or Cool type compared to the Leggette or Ashford type as the former are comparatively smooth inside

We are now in a position to discuss as to how the foundations are undermined. (*See* fig. 6).

Undermining of Foundations.

Imagine a floor with bottom F F′ at the same level as the ground level outside and adjoining it, which is H feet below the normal spring level. The flow from underneath the floor at F′ into the open area F′ G will occur with a velocity=K H (equation iv) where K is a constant. The sand wall or column F′ M will act as a strainer and the depression curve, showing the pressures under the floor, will take the shape $\gamma_o\ \gamma_o'$ the depth of this curve below the normal spring level = h_e indicating the head which produces the flow at any point P_o under the floor. This curve of depression $\gamma_o\ \gamma_o'$ will be very nearly the same as the curve of loss of head and will be a symplotic to the normal spring line. The length F′ P_o along F F′ from F′ as zero being approximately the same for any depression h_c as the depth F′ P′ for a loss of head h_c. This should be very nearly correct as the loss of head at each point is a function $\phi\ (y)$ of depth or length of floor, being H— (y).

If V_c is the critical velocity the soil particles from underneath the floor will be disturbed to a distance F_o.

Where $V = V_c$ and $h = h_c$ the critical head so that a crack will occur near but beyond this point of critical velocity. This process will gradually go on till by stages of degradation the settlement will reach the face wall of the siphon or other work and endanger the main structure, (mark the first crack on Jauryan siphon central wall which has occurred where $h_e = 13''$)

Effect of End Curtain Walls.

toe wall to a depth occur with velocity Kh_1, and the depression curve will be $y_1\ y_1'$ with a critical head h_c occurring at P_1. As Kh_1 is greater than V_c, the dislocation of particles will still continue and a crack will occur near P_1

If the sheet piles are driven to ... the depression curves over the floor will be ... P_2 The structure ... es are carried furt ... ch that $kh_4 = vc$, the flow from underneath the piles will occur with a velocity less than the critical and therefore there will be no dislocation of soil particles and the structure will be safe The problems is to determine the critical velocity and critical head for different types of foundation soils. That known, the design of the depth of toe wall or the piles, is a simple matter. With the help of the loss of head curve, h_c can be easily determined for each site by a series of observations with pressure pipes keeping (H) the depth of discharge water below normal spring level, as near the maximum as is likely to occur under the worst conditions. If the piles are carried a little lower than the calculated depth it will add to the stability of the work by giving a factor of safety.

That the above is in keeping with actual facts is clearly borne out by the relative pressure diagrams, under the pacca floors of the Dugri and the Jauryan siphons. The Dugri has a curtain wall of sheet piles 8′ below floor and the Jauryan has a curtain wall only 2′ 5′ below the bed consisting of wells. Compare photographs No 5 and 6 In the Dugri the pressure gradient under the floor follows the normal gradient till the end reach where it curves down to the sheet pile line. The fact of pipe No 5 always recording pressures below the normal gradient line was thus clearly explained. In the Jauryan the depression from the normal gradient line starts from near the face of the barrel. This is due to the shallow toe wall under which the velocities are higher. The dotted lines in both pictures give the normal gradients.

Under the Dugri floor the uplift or "**blowing up**" pressures are

blowing up" pressures have been reduced but the blowing out pressures have been dangerously increased If H be the drop below the normal Gradient line to the apparent water level or the cunette water level at any point H_s the "**blowing up**" pressure or static Head and H_v the "blowing out" pressures or kinetic Head at that point then,

$H = H_s + H_v$ Since H is constant for any set of given conditions, H_s will increase or decrease by the amount of decrease or increase respectively, of H_v. In syphon floors H_s can be cheaply provided for by giving extra reinforcement in the floor slab but in Weirs, where gravity sections are necessary, the relative weights of H_s and H_v become very important and must be carefully considered Increase of H_s means great expense and increase of H_v endangers the structures by undermining

A safe mean can be obtained by somewhat reducing the thickness of floor and correspondingly adding to the depth and length of the inverted filter, depending on the depth of the toe wall which will govern both H_s and H_v.

It must, however, be clearly understood that the normal gradient

gradient p...

is of universal application.

It might be mentioned here that **Bernoullie's Law holds in case of subsoil water flow** just as much as in the case of free water flow, only the interpretation is more complicated.

Wells Versus Sheet Piles.

Attention is invited at this stage to the faulty nature of the wells as curtain wells. They act as efficient anchors—much better than sheet

Undermining of Foundations.

Imagine a floor with bottom F F′ at the same level as the ground level outside and adjoining it, which is H feet below the normal spring level. The flow from underneath the floor at F′ into the open area F′ G will occur with a velocity=K H (equation iv) where K is a constant. The sand wall or column F′ M will act as a strainer and the depression curve, showing the pressures under the floor, will take the shape γ_o γ_o' the depth of this curve below the normal spring level = h_e indicating the head which produces the flow at any point P_o under the floor. This curve of depression γ_o γ_o' will be very nearly the same as the curve of loss of head and will be a symplotic to the normal spring line. The length F′ P_o along F F′ from F′ as zero being approximately the same for any depression h_c as the depth F′ P′ for a loss of head h_c. This should be very nearly correct as the loss of head at each point is a function ϕ (y) of depth or length of floor, being H— (y).

If V_c is the critical velocity the soil particles from underneath the floor will be disturbed to a distance F_o.

Where $V = V_c$ and $h = h_c$ the critical head so that a crack will occur near but beyond this point of critical velocity. This process will gradually go on till by stages of degradation the settlement will reach the face wall of the siphon or other work and endanger the main structure, (mark the first crack on Jauryan siphon central wall which has occurred where h_e = 13″)

Effect of End Curtain Walls.

[illegible] toe wall to a depth [illegible] occur with velocity [illegible] a critical head h_c occurring at P_1. As Kh_1 is greater than V_c, the dislocation of particles will still continue and a crack will occur near P_1.

If the sheet [illegible] over the floor will be [illegible] P_3 The structure [illegible] are carried furt[illegible] that kh_4 = vc, the flow from underneath the piles will occur with a velocity less than the critical and therefore there will be no dislocation of soil particles and *the structure will be safe The problems is to determine* the critical velocity and critical head for different types of foundation soils. That known, the design of the depth of toe wall or the piles, is a simple matter. With the help of the loss of head curve, h_c can be easily determined for each site by a series of observations with pressure pipes keeping (H) the depth of discharge water below normal [illegible] the worst [illegible]

This depression curve of the strainer shows that the strainers are located in the wrong position, for the end of the floor, which it is desired to protect from the dislocation of soil particles, gets practically no relief or at this point the curve has again risen close to the normal spring line the net relief being 0 3 feet If the sheet piles were non-existent this floor will fail inspite of the relief strainers

[illegible]

At the strainer the sheet piles could be theoretically cut down to nothing, as all the pressure will be relieved by the strainer but this is risky, as, if for any reason the strainer is closed or gets choked the full [illegible] the structure unsafe. The [illegible] ing of the strainers along the

Let the strainers be spread x feet apart Taking the section through those along [illegible] figure 10. [illegible] a pressure c [illegible] loss of head

If M is the point of critical head and critical velocity, then the length of sheet piles required will be LM. Any depth below this will be a factor of safety.

Besides relieving pressure from underneath the floor and its end and thus preserving its foundation soil from dislocation a strainer, at this position, also relieves pressure under the open bed outside the pacca floor. This open floor may be an invested filter or pitching. Since water is flowing towards the strainer there can be no tendency for soil particles [illegible]

indicated by the shaded area LMN., (figure 6). Thus at any section P, the pressure tending to blow up soil particles will be PQ and not PR=H.

Apparently the correct policy would be to take the sheet piles up to the critical depth and then give, in addition, strainers for relief.

In case of strainers the very finest slits must be used so as to preclude any possibility of the fine soil particles being carried away, thus causin-

cavitation under the floor, and defeating the very object which the strainers are meant to serve. Also the strainers should be blanked off in clay strata, as no matter how fine the silts are, clay will get into them and cause cavitation under the floors in time If there is doubt about the strainer being absolutely proof against silt intrusion, their insertion must be carefully considered.

Critical Head.

From the foregoing investigation it is clear that the critical head for any class of foundation soil will determine the design of structure on the soil. The question is what is the **Critical Head.**

Colonel Clibborn in his Roorkee experiments found that with Khanki sands the blowing of sand occurs under heads of 1½ to 3 feet, but the experiments not being conclusive no definite law could be established. (Technical Paper Government of India No. 97 of 1902.) (Plate [illegible] which dislocated sand. Again in plate IV, figure 1, the sand blowing occurred at 16 feet head. The normal H G line, in this case, cuts the vertical through the glass pipe 9" above water exit level showing that the head to dislocate sand was only 9" From these it appears that the **Critical Head for Khanki sand is 9".**

Mr. Beresford on page 31 of the same paper [illegible] his opinion based on t[illegible] particles of sand, prov[illegible] one-third of the depth or thickness of sand. Increased head produced turbidity and a further increase to half depth or over caused the sand to blow. The tendency was completely stopped by the addition of 3" to 6" of fine ballast on the surface of sand which was 45" deep." The last sentence contains the **germs of the idea of adding inverted filters** of graded ballast at the end of a pacca floor.

Applying the test of Mr. Beresford to the curve of plate VII the head being 3·8 feet, three times head -- 11·4 feet. The loss of head at that depth is 0·7 feet or 8½".

The class of sand at Dugri I being very nearly the same as the Khanki sand the agreement between 8½" and 9" is satisfactory.

Parker in his control of water (page 299) gives L = 3·6h for sands of the Khanki type. This from the curve will give a still lower value of critical head.

The critical head for the Punjab sands may therefore be accepted from 6 inches to one foot.

This Critical Head will obviously be greater for coarse sand, gravels etc.

Critical Gradient.

Like the critical head, there is a critical gradient for each class of soil. *If the hydraulic or pressure gradient of flow exceeds this critical* gradient at any point the velocity will be higher than the critical and the soil particles will start moving beyond that point In the case of the curve of plate VII this critical gradient for a depth of 11·4′ (which has been assumed to be the critical depth) is very nearly 1 in 9. With Parker's ratio of 3·6, this gradient is 1 : 13.

Further Scientific Research.

[illegible]

Lahore, and the results will be well worth the labour spent The investigation of critical velocity may be of use but has no practical application in the design of structures.

Surface Water effecting Spring Level.

[illegible]

saturated soils Experiments were carried out at the Dugri and Jaurian siphons to determine the effect of raising and lowering the water level in *the cunette* without changing the canal level with remarkable *results.* These results are confirmed by the available datas of pressure pipes observations at the Narora and Sulemanki weirs.

[illegible]

smaller as the bottom strainer of the pressure pipe goes down or as the distance increases from the toe wall toward the canal (see table below).

Dugri Upstream						Dugri Downstream.				
S No	Bed Level of pipe.	21-7-29	2-8-29	Diff		Bed level of pipe	21-7-29	2-8-29	Diff.	
Canal	W L	95 52	95 52	0 0		.	95.52	95.52	0 0	
Cunette	..	89.54	90 60	1.06		..	88.35	89 9	1.55	
1	778 75	94 12	94 72	0 62		96.3	93 72	94 02	0.28	
2	778.24	94 01	94.59	0.58		70.3	92 94	93.52	0.58	
3	780.20	93 91	94 32	0 41		78 8	93.10	93.53	0 43	
4	779.20	93 79	94 44	0 65	B	78 1	93 01	93 47	0.46	B
Strainer	771 70	93 30	93 98	0 68		78 5	90.36	90 95	0.59	
5	*780 80	93 10	93 55	0.45		74 6	92.86	93.38	0.52	
6	*780 782	91.50	91 69	0 19		82.2	92.57	93 12	0.55	
7	*778.780	92 40	92 90	0.50						
8	763	93.11	93·89	0 78						
9	768	92 98	93.80	0 82	A	B=pipes under floor.				
11	767	93.52	94 09	0.57		A=pipes in open drain bed.				
12	768	93 07	93 86	0 79						
Mean		93 23	93 82	0·59		Mean	92 65	93 14	0 49	

* For pipes 6 & 7, upstream, the filter levels are different on the two dates which accounts for the low differences

A possible explanation for this phenomenon is, that a rise in the cunette water level exerts a back pressure against the general direction [illegible] r. From Ber- [illegible] oward pressure [illegible] d due to the reduced velocities. The practical application of the experimented results and phenomena outlined in this paper, has been dealt with in a separate paper.

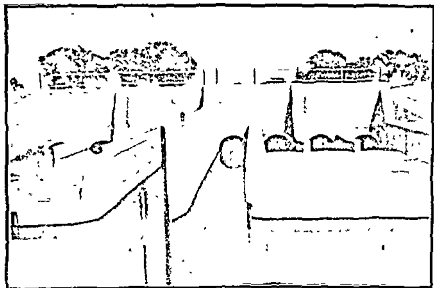


Photo No 1.
Dugri 1 siphon Downstream showing finished structure.
April 1929.

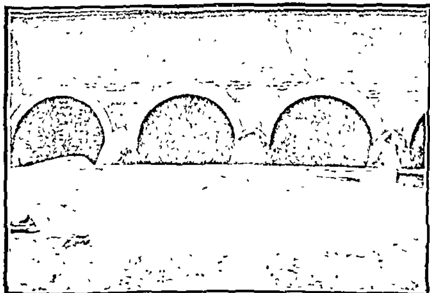


Photo No 2.
Dugri 1 siphon Downstream. Before remodelling January 1929.
Showing cracks in face wall and round barrel rings.

smaller as the bottom strainer of the pressure pipe goes down or as the distance increases from the toe wall toward the canal (*see* table below).

Dugri Upstream					Dugri Downstream.			
S No.	Bed Level of pipe.	21-7-29	2-8-29	Diff	Bed level of pipe	21-7-29	2-8-29	Diff
Canal .	W. L	95 52	95 52	0 0	..	95.52	95.52	0 0
Cunette ..	"	89.54	90 60	1 06	.	88 35	89 9	1.55
1 .	778 75	94 12	94 72	0 62	96 3	93.72	94 02	0.28
2 ..	778.24	94 01	94.59	0 58	70.3	92 94	93.52	0.58
3 ..	780 20	93 91	94.32	0 41	78 8	93.10	93.53	0 43
4 ..	779 20	93 79	94 44	0.65	78.1	93 01	93 47	0 46
Strainer ..	771 70	93 30	93 98	0 68	78 5	90.36	90 95	0.59
5 .	*780 80	93 10	93.55	0.45	74 6	92 86	93.38	0.52
6 .	*780 782	91 50	91.69	0 19	82 2	92.57	93.12	0.55
7 ..	*778 780	92 40	92 90	0.50				
8 .	763	93 11	93·89	0 78				
9 .	768	92 98	93 80	0 82				
11 .	767	93.52	94 09	0.57				
12 ..	768	93 07	93 86	0 79				
Mean .		93 23	93 82	0·59	Mean	92·65	93 14	0 49

B (upstream rows 1–5, downstream rows 1–6) B=pipes under floor.

A (upstream rows 6–12) A=pipes in open drain bed

* For pipes 6 & 7, upstream, the filter levels are different on the two dates which accounts for the low differences

A possible explanation for this phenomenon is, that a rise in the cunette water level exerts a back pressure against the general direction of flow, thus reducing the velocity of flow under the floor. From Bernoullies law, assuming that it holds, the static head or the upward pressure increases by the amount that the kinetic head is reduced due to the reduced velocities. The practical application of the experimented results and phenomena outlined in this paper, has been dealt with in a separate paper.



Photo No 3.
Dugri 1 siphon Downstream   Before remodelling January 1929
Showing cracks in floor SS at sheet pile line and CC Downstream. Note the numerous pipes let in for grouting during previous years

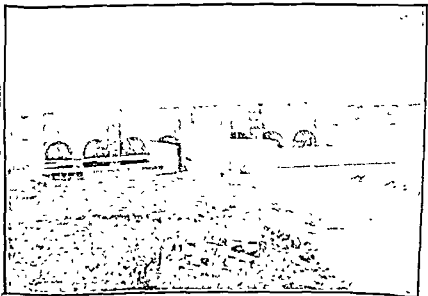


Photo No 4.
Dugri I siphon Upstream completed in January 1929 showing arrangement of pressure pipes for experiments.

Photo No 5

Dugri 1 Upstream (September 1929) showing normal H G. Line (8′ deep toe wall of sheet piles at the end) also effect of a relief strainer (Tej type).

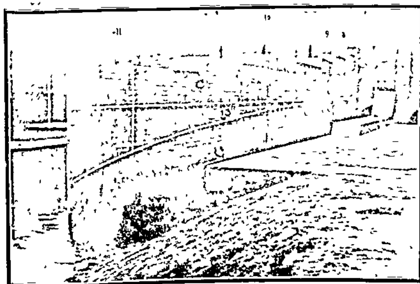


Photo No. 6.

Jaurian siphon Upstream (September 1929) showing normal Hydraulic Gradient line and actual H. G. line. Note the steepening gradient towards toe wall which is shallow. Note also crack C C which has occurred with $H_o = 13'$ at projection of crack where it cuts base.

Photo No 5
Dugri 1 Upstream (September 1929) showing normal H G Line (8' deep toe wall of sheet piles at the end; also effect of a relief strainer (Tej type)

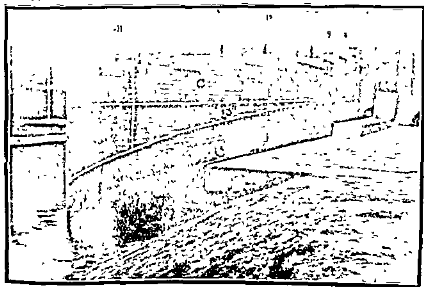


Photo No. 6.
Jaurian siphon Upstream (September 1929) showing normal Hydraulic Gradient ne and actual H. G. line. Note the steepening gradient towards toe wall which is hallow. Note also crack C C which has occurred with $H_o = 13''$ at projection of crack where it cuts base.

DUGRI NO. I. SYPHON UPSTREAM

SHOWING EFFECT OF STRAINER WORKING & CLOSED

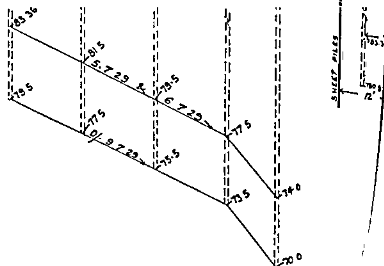
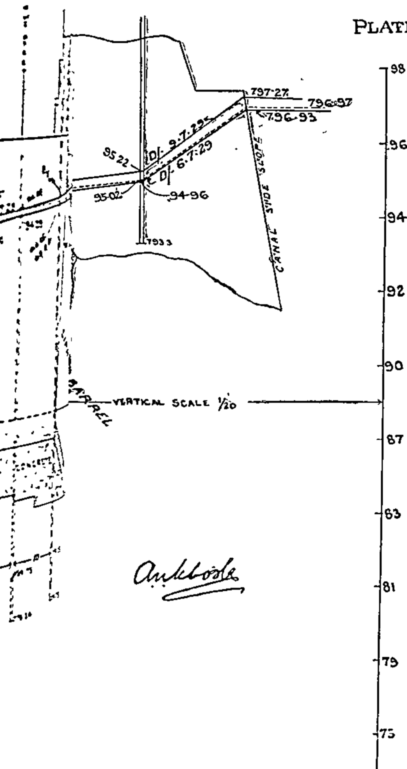
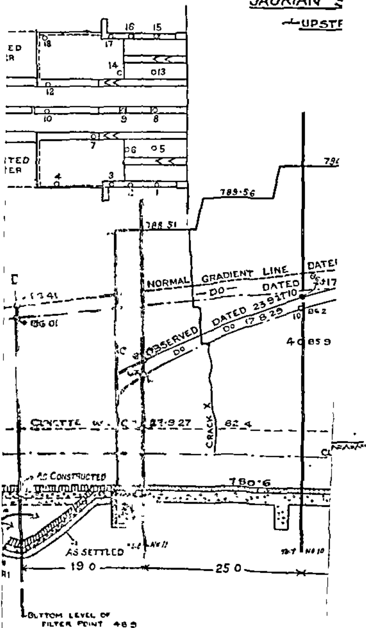


PLATE VIII.



797·27
796·97
796·93
95 22
D/. 9·7·29
D/. 6·7·29
95·02
94·96
793 3
CANAL SIDE SLOPE
VERTICAL SCALE 1/20
98
96
94
92
90
87
83
81
79
75



JAURIAN S
UPSTF
NORMAL GRADIENT LINE DATED
DO DATED
OBSERVED DATED 23 9 1T10
DO 17 8 25
DO
CRACK X
AS CONSTRUCTED
AS SETTLED
780·6
788·56
788 51
19 0
25 0
BOTTOM LEVEL OF FILTER POINT 48 9

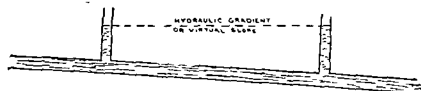
DISCUSSION.

Mr. Khosla in introducing his paper drew attention to the essential features of his theory of subsoil flow. He laid special emphasis on the fact that the equation for the "Loss of Head Curve" proposed by him was of universal application in a relatively wide channel and had received confirmation from Dr. Bose's mathematical treatment of the subject in his paper No 140.

Mr. W. P. Thompson in a written communication said that the

All the elementary books on hydraulics described the "hydraulic gradient" to which also was given the name "virtual slope" by means of an illustration here reproduced

The hydraulic gradient as the illustration shows was measured by the difference in the water levels in the columns connected to the flowing water.



The height of the water level in the column was an indication of the combined static and kinetic energy of the water at each point.

It evidently did not matter how near to the column the water enters or leaves the pipe.

The column applied to the flow of water in a closed medium, as a pipe, gave an accurate enough indication of the state of affairs.

Applied to soil flow which was quite a different thing from a closed medium, the indications might have their value but were only an approximation and in fact the statement on page 141 that the water in the pipes rose and fell with the depth of insertion of the pipe indicated that in

If the hydraulic pressure on the two points P and P′ on two sides of the sheet piles were considered the following results were obtained

(1) for P where $\zeta = \frac{\pi}{2}$

$$\phi p = Vy + Vc\, e^{-\xi}$$

and (2) for P′ where $\zeta = \frac{3\pi}{2}$

$$\phi p' = Vy - Vc\, e^{-\xi}$$

so that the difference of pressure between P and P′ would be given by

$$\delta p = \phi p - \phi p' = 2\, Vc\, e^{-\xi}$$

Now ξ determined the distance of the point P from the sheet-pile along the Y-axis. Taking two points PP′ quite close to the sheet-pile and taking ξ as being very small then

$$\delta P = 2\, Vc = 2\, cki.$$

where k. was the transmission contant and i the slope of H. G; so that, increasing c, the length of the sheet-piles the drop can be increased. Of course this could not go on indefinitely. If c become very long, the effect could be to screen off the flow from the left altogether.

Mr. Khosla had mentioned another fact that there was a piling up of pressure in the upstream [illegible] curvature of the ϕ lines on the pressure line PQ in the diagram [illegible] pressure at P was really equivalent [illegible] vertically over Q which would [illegible] if OA were absent. The stream lines and ψ lines would be as in the absence of the sheet piles shewn in Fig. 2.

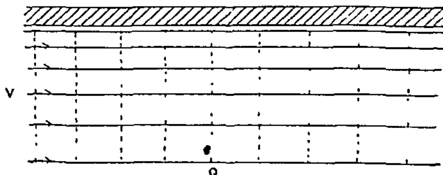


Fig 2

Research Laboratory, it had been shown that the movement of water in a porous medium like the soil can for all intents and purposes be replaced by the motion of a very viscous fluid, whose movement on the free surface follows Darcy's Law of subsoil water movement. It was further shewn in the Memoir that stream-lines and lines of equal hydraulic-head can be represented by two functions ψ and ϕ which satisfy Laplace's Equation *viz:*

$$\nabla^2\psi = 0\,,\ \nabla^2\phi = 0.$$

As their names suggested ψ, the stream-lines, *i.e.,* lines of flow in the medium and ϕ the lines on which the hydraulic head was the same, cut each other at right angles.

Mr. Khosla's experiments on the effect on the hydraulic gradient produced by a line of sheet-piles would be used to verify the soundness of the above theory Mr. Khosla had not supplied any data of his pressure pipe observations for the above case of curtain walls, but the speaker had calculated the probable effect of such a line of sheet-piles of depth c in a medium shown in the diagram Fig. I.

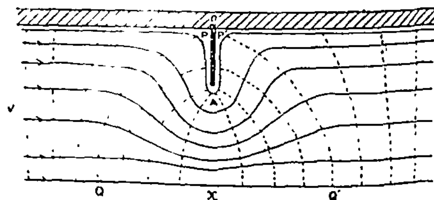


Fig I

In the diagram Fig I the full lines were the stream lines on which ψ is constant and the dotted lines were the lines of equal hydraulic-head on which ϕ was constant, *i.e.,* the hydraulic pressure on them is constant There lines were given by

$$\psi = Vc\ e^{-\xi}\cos\zeta - V_x.$$

$$\phi = Vc\ e^{-\xi}\sin\zeta + Vy.$$

where V is the velocity in the stream, at a considerable distance from the sheet piles, and c the depth of the sheet piles OA. These values of ϕ and ψ satisfied the equations of Laplace, and also the conditions imposed by the above boundary. The quantities ξ and ζ are known as Elliptic co-ordinates and are connected to X and Y by the following equations.

$$X = c\cosh\xi\cos\zeta$$

$$Y = c\sinh\xi\sin\zeta$$

3. Mr. Montagu felt entitled to make a few small corrections in some of the statements recorded by Mr Khosla. The wing walls at Dugri Syphon were not founded on wooden piles, but on a reinforced concrete raft.

The wooden piles were driven to consolidate the slush and to permit of the concrete being laid. The high spring level was perfectly well known and hence the decision to re-build and extend the wing walls.

4. The speaker suggested that the use of relief strainers in works perpetually exposed to hydraulic pressure (p. 139 and elsewhere) was fundamentally unsound. It appeared to him to be sound engineering and ultimately economical, to accept pressures as they existed and design against them. Attempts to relieve pressure by means of strainers invariably had one of two results.

(*i*) The strainer functioned and brought away fine silt and sand, and ended by piping the structures.

(*ii*) The strainer choked up and pressures higher than the design were obtained, to the danger of the work.

Moreover the effect of relief pipes whether fitted with strainers or not was only local. He was pleased to see this so well brought out.

5. The author had brought out the fact that the pressure beneath the floor of a masonry work depended on the height of the Local Spring Water Level (L. S. W. L).

That the emergent velocity depended on this pressure available:

That the soil particles are transported (not dislocated) by the moving water, and that there is a lower limit of velocity beyond which soil particles are no longer moved.

Surely this was a sufficiently large proposition to prove, and would have been sufficient for one paper. Unfortunately Mr. Khosla presented his proposition, his conclusions and his evidence in a way which was extremely difficult to follow.

6. For instance Plate V offers many puzzles

(*i*) Pipes 13 and 14 were driven, apparently to any unspecified depth and left.

(*ii*) Nos. 2, 3, 4, 5 were each given two positions only but three results are given as a pressure curve.

(*iii*) Nos. 6, 11, were the "pressure" lines corrected for depth of point. Otherwise how would they give any indication of the pressures under the floor?

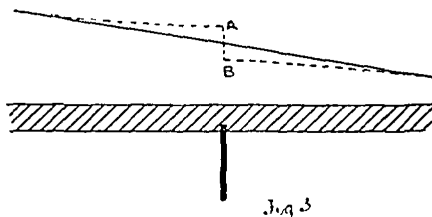
(*iv*) See level 781'5 dated 8th July 1929.

(*v*) See level 781'5 dated 4th july 1929.

of two pipe points.

The corresponding water levels were 791'43 and 791'63 respectively, the difference being due to a difference in bed level of the drain.

Another interesting deduction would be made from the above diagrams. The effect of putting in sheet piles was to disturb the ϕ lines in their neighbourhood and to bend the lines of higher pressure on the upstream side and lines of lower pressure on the downstream side towards the sheet piles. This produced the local piling up of pressure on the upstream side, and the draw-down in the pressure curve on the downstream side. This disturbance, it was apparent, is only local and the ϕ *lines as they recede from the sheet piling resume their normal uniform* spacing. The following diagram showed the pressure-lines in two cases; with and without sheet piling. The firm line was the normal



pressure line while the dotted lines were the pressure lines in the presence of sheet piling at A, B so that the drop in the pressure due to the sheet *piling was only local*

Mr. Montagu began by expressing the view that the paper dealt with a problem, ever present to [illegible] less than fundamental. If the [illegible] to offer they would be directed [illegible] to the basic theory of the paper [illegible]

2. Mr. Montagu then went on to sketch the growth of weir design as it was presented to him as a junior officer just joining the Department. He indicated the necessity for the upstream floor, the downstream floor and the balance between these two.

Subsequent experience, also largely at Marala, had convinced him of the necessity of wells on the downstream edge of the weir glacis and the consequent increase of pressures resulting.

Whereas Mr. Montagu had felt the logic of the facts sketched, he had been unable to produce a theory or a quantitative demonstration on which to found one. This Mr. Khosla had done. He, the speaker, thought he was not overstating the case if he held that prior to Mr. Khosla's paper, engineers had been working in the dark. Now they had the light of coherent, substantiated theory to guide them.

that fineness of the subsoil is of more importance than any other quality and therefore that the minimum

silt
soil } moving velocity V_S was determined for each site in terms of
sand

the smallest " fineness " present.

This was another argument for frankly accepting the minimum velocity V_S (*i.e.*, the maximum permissible) at Mr. Lacey's figure.

11. Mr. Khosla's contention that Bernouilli's theorem holds for subsoil flow was extremely interesting (p. 147).

If Mr. Khosla accepted Bernouilli, then he was guilty of an inconsistency in making use of Darcy's approximation.

12. The speaker could not pass over Mr. Khosla's calculation for V_S on p. 150 without one more remark on this point.

If H_s were 0·75 feet

Then V_S would be 7 f. p. s. which was obviously far too high.

If Mr. Lacey's value for V_S were accepted *viz.* 0·882 f.p.s. then H_s = ·01 feet, a very different figure.

13. Mr. Khosl [illegible]
critical velocity, cri
hydraulic gradient
that a more definite term than critical be applied to the minimum velocity with which he was dealing. He (the speaker) used " Minimum

sand
soil } moving velocity " and designated it V_s
silt

Mr. Haigh said he would like to express his appreciation of the service to engineering that Mr Khosla had done in preparing this paper. The subject was one of great importance to canal engineers and one that was largely shrouded in mystery to the average man.

2. Mr. Khosla's experimental work which to his knowledge represented a great deal of his personal time was of great value to the study of the subject, and while he could not entirely accept the theory Mr. Khosla had based on his results, it represented at any rate an advance on the generally accepted treatment of the subject.

3. *Mr. Khosla's paper chiefly centred round the formula:*

$y = k \log h - c$

where y was the depth

h, which was termed the loss of head was the pressure in excess of static at the depth y, k and c being constants to which he had assigned values.

4. This formula Mr. Khosla had developed from experiments at one or two particular sites and he (Mr. Haigh) was not clear to what extent he considered this formula applicable to other sites.

Surely this was the way they were supposed to be read.

7. The speaker felt that Mr. Khosla had failed to present his "loss of head" curve in a clear manner, and suggested the following simple treatment.

Plot the actual pressure (*i.e.*, head acting) against the depth of the point the former horizontally to a logarithmic scale and the latter to a natural scale. This gave the desired law at once, but he (speaker) ventured to emphasize that the one set of observations presented by the author would only give a particular equation and not a general one. Far more investigations in the field were required to establish a general law.

Referring to p. 143 he said there seemed to be no reason for the expression of the law derived in terms of logs to base 10. The natural base "e" would indicate similarities far more easily and the problem should certainly be examined on this basis.

8. On p. 144 the author proceeded to apply Darcy's law to subsoil flow. Dr. Bose in his paper had proved that it applied only to the surface. To apply it to the body of the water was only the roughest approximation and depended for its accuracy on a very low velocity. But the Author postulated velocities of a high order to move sand particles.

If it was postulated that

$V = Kh.$

and that the Total Energy Line was straight,

then V was constant

i was constant

h was fixed in value all along the path.

In the limit this was absurd.

It followed that either a T. E. line could not be straight, or that the Darcy approximation was not true or that Mr. Khosla's classification of the curve connecting depth and pressure was wrong.

Whichever it may be (and it may well be all three) clearly Mr. Khosla's deduction that

$V \propto h$

was fundamentally untrue and at the best was only a rough approximation. Further deductions on this basis therefore were unjustified.

9. Mr. Khosla's observations on the point of the minimum velocity required to move soil particles (p. 144) might be linked up with the limiting silt moving velocity in Mr. Lacey's Rational Silt Formulae (Paper No. 4736 Inst. Civil Engineer) and Thrupp's experiments on sand ripples: also the aniline dye experiment on viscous flow in the hydraulic laboratory for 1st year students. Mr. Lacey shewed that it was 0·882 f. p. s.

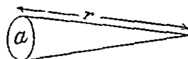
10. The demonstration on p. 146 as to the location of the first crack to indicate failure of floor was obscurely presented but of itself extremely neat, and deserving of careful examination. It appeared clear

The same formula would also give us the discharge of a drain. In this case

$$c = \frac{\pi k m}{n}$$

when m was the length of the drain c = ·004 per foot when k = ·003 an average value In this case R_2 may be taken as half the surface width.

7. As a matter of fact in the case of a syphon outfall he would expect conditions to be more analogous to flow towards a point. Considering conditions of flow in both the vertical and horizontal planes they [illegible] both cases [illegible] flow would be some- [illegible] a point. In that case



$$v = k\frac{d\,h}{d\,r}$$

$$q = \frac{k\,a\,d\,h}{d\,r}$$

Now $a = c\,r^2$ $\quad \therefore\ q = c\,r^2\ \frac{k\,d\,h}{d\,r}$

$$d\,h = \frac{q\,d\,r}{c\,k\,r^2}$$

$$h = -\frac{q}{c\,k\,r} + c$$

$$h = \frac{q}{c\,k}\left(\frac{1}{R_2} - \frac{1}{R_1}\right)$$

C = 4 π for flow in all directions or might be taken as π for the quarter spherical flow of a syphon outfall.

For k = 0·003, c k = 0 00928 = ·01 say.

$$\therefore\ {\cdot}01\ h = q\left(\frac{1}{R_2} - \frac{1}{R_1}\right)$$

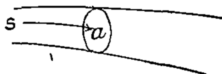
The second term of the bracket being small might be taken as Zero or all practical purposes hence $\cdot 01\ h = \frac{q}{R_2}$

8 Mr. Khosla's results plotted to the logarithmic form, however, indicated that the conditions at site approximated more to concentration in one plane. Probably the bed puddle o· the presence of clay in the upper strata interfered considerably with flow from the canal.

9. Converging flow was always accompanied by a convex pressure gradient which was very steep at the downstream end indicating the necessity for careful consideration of conditions there.

5. The formula, however, merely represented the condition of converging subsoil flow.

If, in any stream tube of subsoil flow



a, p and v represented the sectional area, the pressure in excess of static nd the velocity at a distance from any origin from Darcey's law.

$$v = \frac{k\ d\ h}{ds}$$

and the discharge which is, of course, constant along the stream tube

$$q = va = \frac{k_1\ a\ d\ h}{ds}$$

Now if the area vary uniformly as s,

$$a = k_2\ s$$

$$\therefore q = k_3 \frac{s\ d\ h}{ds}$$

$$\text{or } d\ h = k_4 \frac{ds}{s}$$

when e, integrating $h = k_5 \log s + k_6$

$$= k_5 \log \frac{s}{so} ,$$

6. This was, of course, the same fo mula as Mr. Khosla's—though his y was not necessarily measured along the line of flow—and i the conditions at the site where the experiments were arried out wer examined it would be found that there concen ratio of stre m lines obtained. Considering it in plan they had flow into the bed of the drain from both sides and also from the end under the sypho . floor.

A particular case of this formula was that for the disch rge of a tube well

$$c\ h = q \log \frac{R_1}{R_2} .$$

where R_1 was the radius of influence of the well and R_2 the radius of the effective strainer. In this case

$$c = \frac{2\ \pi\ k\ m}{n}$$

where k was the transmission constant.

m was the length of strainer.

n was 2.3026 the factor for the conversion of ommon to hyperbolic logarithms.

The forces acting on it were—

gravity $= (m-1)\, a\, d\, r\, \frac{d\,p}{d\,r}$ where m is the specific gravity of the soil.

friction $= -(m-1)\, a\, d\, r \cos\theta \tan\phi$ where ϕ was the angle of repose and θ was the angle of inclination of the stream tube to the horizontal.

and pressure $= +\, a\, d\, p$

For equilibrium

$$(m-1)\, d\, p + d\, p = (m-1) \tan\phi \cos\theta\, d\, r$$

$$m\, d\, p = (m-1) \tan\phi \cos\theta\, d\, r$$

$$\frac{d\,p}{d\,r} = \frac{m-1}{m} \tan\phi \cos\theta$$

also

$$\frac{d\,p}{d\,r} = \frac{q}{\pi\, k\, r}$$

and

$$q = \frac{\pi\, k}{n} \quad \frac{h}{\log\frac{R_1}{R_2}}$$

$$\therefore \frac{m-1}{m} \tan\phi \cos\theta = \frac{h}{n\, R_2 \log\frac{R_1}{R_2}}$$

$$h = \frac{m-1}{m}\, n,\, R_2 \log\frac{R_1}{R_2} \tan\phi \cos\theta$$

For a drain of bed width 2′ taking

$R_1 = 100$

$m = 2$

$\tan\phi \cos\theta = \cdot 3$

Then $h = 0\,7$

For bed width 20′

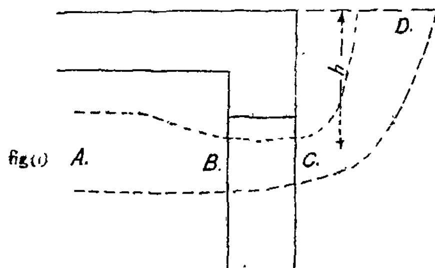
$R_1 = 1{,}000.$

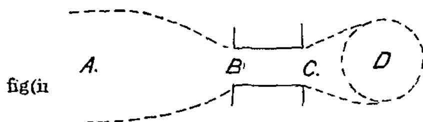
$h = 7{\cdot}0.$

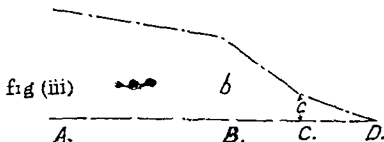
Results which were not inconsistent with actual experience.

15. If the rate of change of pressure were not uniform they had either converging or diverging flow. In the case of the former the rate of change of pressure increased as they passed along the stream line and consequently motion would take place from the point where it exceeded the containing force and, as Mr. Khosla pointed out, the motion would [illegible] by a change of pressure distribution tending to progres- [illegible] flow was divergent they [illegible] contained by the

16. *An example of this might be found in the conditions existing* near the spaces between wells which had not been properly sealed.







[illegible] C, D
to the
At c.
however, they had the weight of the soil capable of exerting a considerablee

horizontal pressure to resist movement. The weight of the soil there would be (m − 1) h − c and the horizontal pressure it could exert would be

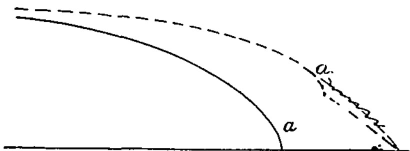
$$\left[(m-1)\,h - c \right] \frac{1+\sin\phi}{1-\sin\phi}$$

where ϕ was the angle of repose.

If h were small, i.e., if the sealing course were shallow or if erosion had taken place downstream they might get dangerous conditions. Danger might also occur if the filling at D were so course that the fine material under the wells could pass through it without restraint.

17. Any change of direction in a stream tube was accompanied by a concentration of flow and consequent increased rate of change of press- [illegible]

18. The case of rapidly converging flow such as occurred downstream of a syphon when spring level was high required very careful consideration. As has been shown there was for every depression head into a drain a minimum bed width necessary for stability. Similarly at a syphon outfall there was a minimum radius necessary to secure the earthern sides of the drain against sloughing, and on account of the more rapid convergence at a syphon outfall (horizontal as well as vertical) this radius was greater than in the case of an open drain. The use of piling in such cases lay in the fact that it increased the length of the hydraulic gradient, provided a region of uniform change of pressure at the end thereof, and also earth pressure to contain the local high rate of change round the bottom of the piles. Such piling was best arranged in a semicrcle, i.e, normal to the line of flow. The pressure gradients obtaining without and with piling would be similar to the full and dotted curves below.



The sudden steepening at a in the curves was due to the change of direction from horizontal to vertical flow.

19. With reference to Mr. Khosla's para. 2 or p. 145, the rate of inflow per foot length of strainer would only increase with the depth when the Sub-soil water surface was free in the vicinity of the well and vertical flow took place. This occurred, of course, in the case of seepage drain relief pipes, but not in the ordinary tube well.

20. While on the subject of this para, he would like to ask Mr. Khosla if he had any data on which to base his statement that the loss of head in a Leggett or Ashford Strainer is much greater than in a Tej or Cook strainer? Such figures might also show whether the loss of head in either case was sufficiently large to have any appreciable effect on the flow.

Bhai Bakhshi Singh Sidhu said that Mr. Khosla deserved to be congratulated for boldly declaring that "our existing conception of the law of flow of water through subsoil as affecting the stability of structures resting on saturated soil is far from being correct or complete." The statement had, however, not been printed in bold type like so many other statements to which the author wished to draw attention more prominently. He (Mr. Khosla) had proved from observational data that "accepted theory, established practice and the principles of both are not quite convincing." Mr. Bligh's theory of Hydraulic gradient had been accepted for quite a long time as furnishing an explanation of certain failures and affording a basis for calculations for new designs and repairs to damaged or threatened structures.

Mr. Khosla, had pointed out that due to a rise in the spring level originally safe structures might become unsafe. This factor he did not

outfall or approach channels might be considerably lowered by sub-soil flow into the drains leaving the static pressure under the various parts of the structures unaffected appreciably.

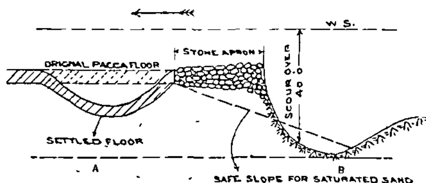
In order to take into account the effect of spring level it would have been very instructive if variations in water surface level in the pressure pipes caused by rise and fall of the spring level round the structures had been analysed and commented on.

The speaker was fortunately not a believer in the hydraulic theory to which Mr. Khosla seemed to cling while exploding its exposition by Mr. Bligh. In support of his view he mentioned the following :—

(*a*) Early that month a portion of the upstream impervious floor of the Balloki Barrage was laid bare and fine cracks in the mortar joints
[illegible] There
r was
: feet
above the floor level Normally for months and months together the difference in water surface level above and below the barrage was over 15 feet The downstream floor was free from any cracks at all, although there was quite a large number of pressure relieving pipes fixed there.

(*b*) Another kind of damage discovered was subsidence of a port on of the upstream pacca floor at its upstream end next to the loose stone apron which apron was almost undisturbed

It would serve no useful purpose to theorise as to the cause of this on incomplete data but the fact remains that Mr. Khosla's new theory like Mr Bligh's time honoured theory did not afford any convincing explanation for the above described classes of damage. The diagram which is reproduced below may help to point out one of the directions in which



to look for the cause (Notice the side slope of saturated fine sand under water and calculate horizontal pressure at A. and B.)

Heavy expenditure had been incurred on several masonry works
[illegible] ig any appreciable
:ise a good deal of
apparently based
on observations at two works in a particular locality and dealt with only a particular aspect of the problem.

Mr. Nand Gopal said that the subject of the paper was interestin and important to any engineer who has anything to do with water! He was afraid that the heading of the paper was the only thing that,

had understood thoroughly and his remarks were based on that understanding. He said that Mr. Khosla called his paper "HYDRAULIC GRADIENTS IN SUBSOIL WATER FLOW IN RELATION TO STABILITY OF STRUCTURES RESTING ON SATURATED SOILS." He did not think this was quite correct. Mr. Khosla's experiments were all carried out near a large Canal where there was direct

[illegible]

risen to about 3 or 4 feet of the surface. He asked Mr. Khosla if the latter had anything to say about this.

Mr. Colyer asked whether the author thought that the puddling mentioned on page 137 would have been effective, had it been executed.

Similar puddling work at Khambi Culvert on the Upper Jhelum Canal had proved effective at the time (1928), and perhaps Mr. Dhody would say if this result had been sustained.

[illegible]

page

divic

soil

After commenting on this valuable addition to Hydraulic Engineering knowledge, he compared the author's theory with that of Bligh; he said that Bligh's seemed to be based *entirely* on the prevention of the transportation of sand particles *along the line of enforced creep ; viz,* along the line of contract between the structure and the soil, whereas the author appeared to have considered primarily—perhaps exclusively—the whole percolation area of the soil beneath the structure and to have omitted any consideration of the line of contact between the soil and the structure, which Bligh evidently held to be the line of least resistance and the source of failures. The speaker suggested that a complete theory should comprise both these considerations, and illustrated this need by the case of the wing-walls of a distributary 'head' built in a Main Canal of which the banks were of sand. If the creep-line, or rather the area of contact between the masonary wings and the canal bank was made only of the same section as would just prevent seepage through the bank itself, it was most likely that the 'head' would fail by 'piping' along the plane of contact of the wing-wall and the bank.

Bligh, on the other hand, appears not to consider the effect of what the author has called the 'free-water-surface,' and which he shows to be of the greatest importance.

The speaker had discussed with Mr. Wilsdon the probable effect on the Sutlej Valley and other weirs, of an almost inevitable rise in the

subsoil *water-level, and had come to the conclusion that many works* which so far had given no trouble would be subject to very different conditions of pressure when equilibrium of the subsoil water level in their vicinity had been reached.

He would be obliged if the author *would briefly describe* the use of the water-jet, and the method of plugging the spaces *between wells* mentioned on page 148.

With reference to page 140 of the paper **Mr. A.A. Musto** said that High Velocity at exit could only exist if *piping* had already started, or if the creep co-efficient taken for design were too low.

With reference to page 147-148 he said that wells had little or no *advantage over piling, as foundations or anchorages for a masonry or* concrete block floor, since once piping started and the subsoil was removed form one edge, they would settle and fall as easily as piling, if not more so, as their great weight would tend to over-turn them; whereas the piling would hang on to the masonry above it and in which it was embeded. *As watertight curtains, wells were most difficult* to make effective, and were unlikely ever to be as good as well-driven piling, while the wells were infinitely more expensive.

The first essential for protection of the floor was a *long* and *thick* apron of pitching stone which would fall, *at a long distance* from the work and thus prevent retrogression of levels near the solid structure. This was needed both upstream and downstream. but, of course, more *so on the downstream side.*

In *replying* to *criticisms,* **Mr. Khosla** first dealt with Mr. Nand Gopal's remarks that in saturated soil the pressure indicated in a stand pipe did not show any variation, no matter how deep a pipe was driven in the ground. This would naturally be so unless the deep soil was excavated some depth below the normal spring level, which would create a difference of pressure and then give varying pressures for varying depths to which the pipes might be sunk.

Dealing with Mr. Colyer's remarks, he said that puddling would *only stop local leakage,* but would not at all affect the subsoil level all round.

Regarding, 'creep' he said the question was receiving attention, and practical tests were to be carried out in the laboratory, also the *mathematical* treatment was being undertaken by Dr. Bose.

Replying to Mr. Thompson, Mr. Khosla agreed that other engineers in the past had treated the Bligh theory with suspicion. He did not mean

to be unfair to the service. All he r
fair proportion of the profession di
theory without regard to its limitatic
law or rather its extension to subsoil
on in reply to Mr. Montagu's, criticism.

In reply to Dr. Bose, the author expressed his indebtedness for the mathematical proof produced by Dr. Bose for the physical phenomenon of local drop in pressure at the sheet-piles, the piling up upstream and the drawdown downstream, which
walls. The pressures above and bel
were a clear demonstration of this.
the Narora weir (Plate II of paper

Dr. Bose had evolved an equation

$$\delta p = 2\,vc \qquad \text{(B)}$$

$$= 2k\,\frac{dh}{dy} \times 2\,c \quad \text{since } v = k\,\frac{dh}{dy}$$

If $\frac{dh}{dy}$ were constant, which would be the case, as nearly as possible, with a deep toe wall at the end, then p or drop of pressure at the piles
Bligh with the
'i' and that the
the intermediate
piles was local was worth remembering. From this, equation, given the drop at the sheet piles and the length of piles, the velocity of subsoil flow can be found, as

$$v = \frac{\delta p}{2c}$$

cally
This

The author reserved for the second paper his discussion of the effect of end piles with the help of ψ lines.

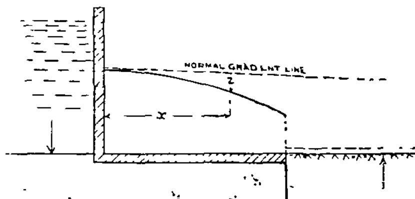
Dr. Bose in his paper No 140 on the Exponential Law of Subsoil Flow, had given the general equation.

$$u = -\frac{1}{\alpha\mu}\,\frac{\delta}{\delta x}\,(P - g\,\rho z) \ldots\ldots\ldots \text{(C)}$$

For the free water surface, $p =$ constant

hence $u = K\,\frac{dz}{dx}$ ....(D).

Which corresponded to the horizontal flow under a flat floor and agreed with what the author had stated on page 147 of his paper.



Next taking the case of vertical flow along axis of Z, p would be changing and the flow would correspond to the experimental one of Dugri I The equation would then reduce to

$$w = \frac{1}{\alpha^2\mu}\ \frac{\delta}{\delta z}\ (p - g\ \rho\ z) = \frac{1}{\alpha^2\mu}\ \frac{\delta p}{\delta z} - C$$

$$= k\frac{dp}{dz} \quad - C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (E)$$

This equation furnished the justification for the assumption $V = K\frac{dh}{dy}$ *viz*, equation (*iii*) of page 144. Darcy's law applied, with all its limitations to horizontal flow only. Bose's law was therefore a more appropriate authority, for such assumption in the vertical direction both upward and downward, as also for general application in the horizontal direction as further explained in reply to Mr. Montagu's criticism.

Replying to Mr. Montagu's criticism, the author thanked him for his appreci[illegible]
a believer [illegible]
the main c[illegible]
of Dugri [illegible]
these, knew better.

The Author fully agreed with Mr. Montagu regarding the risk involved in the use of relief strainers and had already given reasons for that in the text.

Regarding Plate V, the pipes 13 and 14 were driven to 4 feet below spring level in the bank and were not moved. It was, however, found that the occurrence of the face wall and the masonry floor underneath the barrels prevented any direct connection between pipes 13, 14 and 1, 2, 3, etc. Strictly speaking a correction had to be applied to the

readings in pipes 13 and 14 to allow for the fact that they were located in the middle of a masonry floor and above it whereas the pipes 1, 2, 3, etc., were located in the subsoil below the floor. On account of this uncertain factor, this part of the investigation was not pursued any further.

The two positions of the pressure pipes 1, 2, 3, etc., indicated the bottom and top of the filter lengths which varied between 2 and 2 5 feet. These pipes were fixtures. The three pressure curves related to different water levels upstream and to different dates in order to connect these results with the observations on pipes 6 to 12, in the open bed.

Regarding Nos. 6 to 11, the lines below the bed indicated the bottom levels of pipes and the lines above the bed indicated the pressures recorded for those depths. Each individual pipe had been separately treated for loss of head curve. The pressure lines of plate 5 were just to indicate the general features. Thus on 4th July 1929, pipe No. 8 had its filter point at R. L. 781·5 and the pressure recorded was 701 63; on 8th July 1929 the point was at R. L 777·5 and the pressure rose to 792·43; on 15th July, 1929 the point level was 770 5 and the pressure rose to 792 88 and on 12th July, 1929 the filter point level was 765 5 and the pressure recorded was 793·1.

The author agreed with Mr. Montagu's suggestion of trying logarithmic plotting. This would have saved the author a lot of time if he had attempted it in the first instance. [illegible]

This was dealt with at length in reply to Mr. Haigh's criticism. The Naperian base 'e' was certainly better and more logical but the base 10 was taken as the engineer was generally more familiar with the latter. The logarithmic equation could as well be expressed as

$$h = Ke^{y} \quad \text{where} \quad h = \text{loss of head}$$

y = depth of filter point and
K = constant.

Darcy's law had the limitations given below. His experimental work was restricted to flow through horizontal pipes of uniform section or between two horizontal planes. The flow was horizontal. The pressure indicated, related to the points at the top of the soil in contact with the underside of the upper plane.

His law was naturally linear with a uniform rate of change of pressure. No mathematical solution existed, to the author's knowledge, to justify its application to a varying rate of change of pressure The relationship $V = k\frac{dh}{dl}$ was therefore an extra-polation of the Darcy's form $V = k\frac{h}{l}$ The author was here open to correction, but if his surmise

as above was correct, then the credit for this advance of a fundamental character would naturally go to Dr. Bose who in his paper No 140 on the " Exponential Law of Subsoil Flow " had evolved a universal equation for a varying rate of change of pressure, which held both on the free surface and for any point in the body mass and for all directions. This law was experimentally and mathematically correct. The further application of this law had already been discussed. *Mr Montagu had evidently not* followed the arguments of page 147 which dealt with the two component parts of the total energy The total energy line was represented every-

law $V = k \frac{h}{l}$ would STRICTLY hold. But directly the flow was altered by pumping out from a strainer or in-filteration gallery or by digging a drain anyw

flow would change.

strainer, gallery or dra

non-uniform and would obey, not the Darcy linear law but the more general *Bose Law* Whereas the total energy line still followed the linear law, the free surface as indicated by pressure pipes' water levels followed a curve such that the intercept between the total energy line and this curve represented the kinetic or velocity head and the intercept

would certainly give it the appearance of being inconsistent, the Bose's Law explained and established it beyond doubt.

The calculations of Mr. Montagu in para. *12* were not clear to the author.

In reply to Mr. Haigh, the author expressed his sincere thanks to him for appreciating the author's service to the profession in presenting his paper. Mr. Haigh's criticism was in itself an advance and a

Dr. Bose in his paper had stated that in subsoil flow, the ϕ curves were identical with the curves of equi-hydraulic head. In his criticism of this paper he had said that the ψ and ϕ functions satisfied Laplace's equations, *viz* :—

$$\nabla^2 \phi = 0$$
$$\nabla^2 \psi = 0$$

There were two solutions to the equation $\nabla^2\phi = 0$, *viz.*,

$$\phi = ke^{-r} \text{ or } A \log \phi = B - r \text{ or } r + A \log \phi = B$$

for two dimensional co-ordinates,

and $\phi = \dfrac{k}{r}$

[illegible] s the vector.
[illegible] hyperbolic
[illegible] al direction,
[illegible] nward flow
were obtained

In this connection attention was invited to the loss of head curve for the Jaurian Syphon (Plate A) As would be seen from the plan of Plate X, the pipes were in the bed of a narrow drain and the effect of flow from the sides came in A cross section of the drain with location of pipes A and B was also shown for [illegible]
vergent flow towards a point [illegible]
mic scale approximated to [illegible]
R. L. 74, *i e*, at the junction of coarse and fine sane strata. The actual flow possibly followed a curve which was a cross between a hyperbolic and a logarithmic curve, the former predominating. The results were not sufficiently exhaustive for generalisation It might also be noted that the bed of the drain at the Dugri was over 50 feet wide so that flow from the sides was comparatively very small and the conditions approximated to the logarithmic.

Mr. Haigh's treatment of the actual process of soil dislocation with reference to specific gravity of soil was highly interesting and instructive. The [illegible]
down [illegible]
of exi [illegible]
and u [illegible]
spring formation all over the area with pockets of no flow in between [illegible]

soil at the toe of a dam to the upward pull of outflowing water overbalancing the downward pull exerted by the force of gravity. On page 42 of his

paper, dealing with the possibility of erosion and deposition along geological boundaries within the subsoil, he remarks that "the failure of weirs resting on stratified materials sometimes occurred several years after the water
rials
rials,
weigh
loss o
at eac
velocities or in the relative magnitudes of the upward and downward pulls of water and soil respectively.

Regarding the statement about the Leggett and the Tej strainers, the Author had no data to support it and as such did not suggest any great importance to be attached.

In reply to Mr. Bakhshi Singh Sidhu, the author referred him to pressure pipe No. 11 of Dugri Siphon which as stated on page 142 was 120 feet away from the siphon face and recorded much the same normal spring level as elsewhere near the siphon (see plate V). As to the upstream floor of Balloki weir, with a head of 4 feet outside the ring bund, water would naturally ooze out from the cracks in the floor enclosed inside the ring bund

The damage to the "pacca" floor adjoining the loose protection
foundation soil underneath the
over, into a local scour hole
dge would perhaps clear this
point.

The author had not attempted to lay down definite laws. He had simply invited attention to fundamentals and had stressed the need for further experimental work. The deductions of the paper should be accepted only so far as actually proved in the text Mr. Sidhu was quite correct in drawing attention to this aspect.

The author thanked Mr. Musto for his taking part in the discussion and associated himself with Mr. Mursto's remarks regarding long and thick aprons of stone upstream and downstream of a pacca work.

The President in winding up the discussion on Mr. Khosla's paper, said that he believed that all present would agree with him that they were much indebted to Mr. Khosla for his introducing this very interesting and important paper, which had evoked the interest and ingenuity of the mathematicians and the engineers and he hoped that the discussions which had taken place would help greatly in throwing further light on the subject.

STATEMENT A.

Statement showing bottom levels of filter points of pressure pipes at Dugri I Syphon

Date.	Pipe Numbers						
	6	7	8	9	12	10	11
	R. L of bottom of filter point						
.	775	778	780	782	..	784	785 5
2-7-29 ..	774	777	779	781	779	783	784 5
4-7-29	772	775	777	779	779	780 86	783 5
6-7-29	770	773	775	777	777	779	781·5
8.7-29 .	768	771	773	775	775	777	779·5
11-7-29 ..	765	768	770	772	772	774	776 5
13-7-29 ..	778	776	768	770	770	771	773 5
15-7-29 ..	780	778	768	768	768	768	770 5
18-7-29 ..	780	778	763	768	768	708	767
1-8-29 ..	782	780	763	768	768	..	767
6-8-29 ..	781	783	763	708	768	..	767

PAPER No. 139.

SOME INTERESTING TUBE WELLS ON THE NORTH WESTERN RAILWAY.

By

J. VARDON,

Member of the Institute of Water Engineers, Executive Engineer, North Western Railway, Lahore.

Introduction.

In a Paper presented to this Congress last year on " Locomotive and Drinking Water Supply on the North Western Railway," the writer endeavoured to emphasize the urgent need for a Provincial Ground Water Division, to advice and help the public in developing the ground water resources [illegible] act as a [illegible] with Grc [illegible]

2. Such a division [illegible] carrying out experiment[illegible] branch of engineering, a[illegible] the correctness of existin[illegible] water supplies, as well as improve the technique of such work.

3. Some progress has been made along these lines by the Irrigation Department of the P. W. D., but outside the Departmental Circles concerned, very little is known of their activities, even to the men dealing with similar work in other Government Departments.

4. During the past few years, large sums of money have been spent by the N. [illegible] e possibilities of obtaini[illegible], where such supplies a[illegible]

5. These trial borings constitute experimental work in one sense only. They establish the possibility of obtaining a supply of water at the particular locality. They do not provide any information that would advance our knowledge of Tube Well engineering. The scope for experimental work of this nature is vast, but such work would require careful planning, a trained organization, and ample funds. The benefit that would be derived from such expenditure may not be available for some considerable time, and in many cases would not be of sufficient direct value to the Railway to justify us in undertaking work of this nature on even a moderate scale.

6. Where conditions warrant investigations and experimental work, for the purpose of improving existing watering arrangements and the prospects of success are reasonable, the Railway authorities have always been willing to provide funds. In some cases the experiments made have not been successful, but in others success has been very [illegible] and resulted in savings large enough to justify all the experimental that has been done.

STATEMENT A.

Statement showing bottom levels of filter points of pressure pipes at Dugri I Syphon

Date.	Pipe Numbers						
	6	7	8	9	12	10	11
	R. L. of bottom of filter point						
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2-7-29 ..	774	777	779	781	779	783	784 5
4-7-29	772	775	777	779	779	780·86	783 5
6-7-29	770	773	775	777	777	779	781·5
8.7-29 .	768	771	773	775	775	777	779·5
11-7-29 ..	765	768	770	772	772	774	776 5
13-7-29 ..	778	776	768	770	770	771	773 5
15-7-29 ..	780	778	768	768	768	768	770 5
18-7-29 ..	780	778	763	768	768	768	767
1-8-29 ..	782	781	763	768	768	..	767
6-8-29 ..	784	783	763	768	768	..	767

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2. Such a division would naturally develop into an organization for carrying out experimental and research work in all the phases of this branch of engineering, and would be in a position to establish or refute the correctness of existing theories on the different aspects of Tube Well water supplies, as well as improve the technique of such work.

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4. [illegible] by the N[illegible] of obtai[illegible] supplies [illegible]

5. These trial borings constitute experimental work in one sense only. They establish the possibility of obtaining a supply of water at the particular locality. They do not provide any information that would advance our knowledge of Tube Well engineering. The scope for experimental work of this nature is vast, but such work would require careful planning, a trained organization, and ample funds. The benefit that would be derived from such expenditure may not be available for some considerable time, and in many cases would not be of sufficient direct value to the Railway to justify us in undertaking work of this nature on even a moderate scale.

6. Where conditions warrant investigations and experimental work, for the purpose of improving existing watering arrangements and the prospects of success are reasonable, the Railway authorities have always been willing to provide funds. In some cases the experiments made have not been successful, but in others success has been very marked, and resulted in savings large enough to justify all the experimental work that has been done.

7. It is the intention of the writer briefly to describe a few wells that he considers would be of special interest to those dealing with this branch of engineering, and of general interest to all engineers.

8. It is felt that these descriptions may in some measure help others to solve similar problems when they are encountered, and may lead to improvements on the methods adopted by the Railway, with correspondingly better results, which would benefit engineers working on Tube Wells.

The wells it is proposed to describe are located at—

Laki Marwat.
Rohtak.
Campbellpur.
Lyallpur.
Umballa Cantonment.

Tube Well at Laki Marwat.

1. This well is of special interest, in that it was the first effort I knew of in the Punjab, to gravel shroud a well after it had been installed

2. Those of you who have read the Paper on "Locomotive and Drinking Water Supply on the North Western Railway" will remember the description of Air Made Gravel Wells which were observed in the U. S. A. and the efforts made to install similar wells on the North Western Railway at Rohtak and Umballa Cantonment

3. The well at Laki Marwat was installed in 1924, a year before the formation of the Special Tube Well Division.

4. The strata drilled through was analysed by Mr. Ashford of Amritsar, and the location of the "Ashford" Screens used, was determined by him. His estimate of the probable yield from the well was 7,000 gallons per hour, with a "Drop" of 7'-0".

5. The well was tested by the Divisional Engineer with a [illegible] was only 1,000 gallons per hour. [illegible] that the well was a failure, and the [illegible] then been formed, was ordered to take over the well and withdraw the Strainers and Plain Pipes.

6. Before doing this, it was considered that a further test should be made with a more suitable pump than the Centrifugal used for the first test.

7. An Air Lift Pump was arranged, and on test an yield of 4,000 gallons per hour with a 36'-0" "Drop" was obtained, but as very large quantities of sand were being drawn through the strainers, it was feared that serious cavitation would occur, which might result in damage to the fragile "Ashford" Screen.

8. It was therefore decided to stop further pumping and endeavour to gravel shroud the Screen through two 4" pipes sunk on either side of the well.

9. This was done and pumping restarted. For the first two days the gravel in the 4" tubes did not move, but on the third day the tubes were tapped, and the gravel moved down very rapidly The tubes were refilled as the gravel moved down and altogether 42 c ft were fed down in this way.

10. The yield from this well is now 6,500 gallons per hour with a "Drop" of 44'-0'. The water delivered is quite free of sand and the well has been in regular use since 23rd August 1928. A sketch of the well showing the location of the strainers and gravel tubes is appended.

11. The sand from which the water is being drawn is very fine and there is an appreciable proportion of clay in it

[illegible]

to his error in using a screen with too wide slots

13. The description of the well at Laki Marwat indicates how troubles from similar sanding wells may be overcome, but it is almost essential to use an air lift pump for this purpose, as sanding causes no trouble to such a pump

14. A somewhat remarkable feature of this well is the depth at which the shrouding was done, with the relatively small bore of gravel tubes used This will be better appreciated by those engineers who may be called upon to deal with a similar problem. It will be found, that although large quantities of sand are being drawn through the screens, gra [illegible]
arc [illegible]
the [illegible]
of [illegible]

15. A simple calculation will show that if the gravel fed down the tubes distributed itself evenly around the 56'-0" of screen, (the gravel could not get down to the lower length of 16'-0" of screen) it would only form a shroud 3" to 4" thick, sufficient however to keep the velocity of the water outside the shrouding below the "Critical Velocity" of the sand.

Tube well at Rohtak.

1. The tube well at Rohtak was the first air made gravel well attempted on this Railway and perhaps the first of its kind in India.

2. It was installed by my Sub Divisional Officer during my absence on leave, in accordance with a written description of the procedure to be adopted, sent out by me after studying the methods in the U. S. A. An account of it is to be found in the Paper presented to the Congress last year.

3. At that time the permanent pumping plant for this well had not been provided Development was completed, and the yield test showed that 5,000 gallons per hour could be obtained from it with a drop of 20'-0".

4. The 6'-0" length of screen used was made up in the Railway Shops from an ordinary 6" pipe, in which were milled 75 longitudinal slots each 4" × ⅜". The yield per square foot of screen used, works out at 550 gallons per hour.

5. The air lift *cum* centrifugal plant provided for this well was erected and was due to be tested on 25th April 1929.

6. After a short run the plant was shut down, and when restarted, [illegible]

7. This came as a shock to us, and appeared to be a very serious set back for this type of well. As the permanent pumping plant had been supplied, something had to be done to provide a well from which this plant could pump water

8. It was immediately decided to resort to [illegible] tubes of 6" bore were sunk around the well to the top of the screen, as shown in the diagram appended. They were filled with gravel to a depth of 8'-0". The cost of doing all this work amounted to about Rs. 300

9. The Air and Eduction pipes were again lowered into the well, and pumping restarted No gravel moved down the well although a considerable quantity of sand was pumped out Arching of the gravel in the tubes was believed to be the cause of this, and it was decided to sludge out the gravel, clean the tubes and refill them to the top

10 During the process of sludging it was found that sand had worked up into the gravel tubes, and formed, with the gravel, a semi-solid mass, which blocked the end of the tube and prevented the gravel moving down.

11. Before refilling the tubes with gravel, the sand was cleaned out to a depth of 3" to 6" below the bottom of the tubes, to ensure an open clear outlet for the gravel, which was then filled to the top of the tubes, and pumping restarted

12. As sand was pumped out, gravel moved down the tubes, and this continued till 55 c. ft. had been fed down as a result of about 80 hours pumping.

13. Sanding has almost completely ceased, except when the well is "Back Blown" when a very small quantity is drawn into the well and pumped out. This sanding lasts for about ten minutes only, after that the water is again quite clear.

14. When the well was installed in 1928, during development 50 c. ft. of gravel was fed around the Screen, which with the 55 c. ft. added in May last, makes a total of 105 c ft.

15. If this quantity has distributed itself uniformly around the 6'-0" length of 6" screen, there [illegible] and I am inclined to believe that [illegible] exist around the screen now, as [illegible] screen is located would have to be some distance from it, for the velocity of the water flowing through it to be below the "Critical Velocity."

16. It was not possible for me to verify this by actual boring, as [illegible] ll, and we [illegible] thickness [illegible] communicated to any of you who may be interested It may be that similar experiments will be made by other engineers of the Punjab. I am sure several of us here would be obliged if the results obtained could be published or communicated to us individually.

Tube Well at Campbellpur.

1. The first attempt to replace the existing Railway Water Supply from a 20'-0" dia open well, by a tube well, was made in April 1925.

2. The boring was sunk with a hand outfit, using 13" casing pipes. These could not be sunk below 150'-0" owing to a layer of large boulders struck at this level.

3. A tube well with 10" Ashford Strainers was lowered into the boring, and the well tested for yield with an Air Lift Pump.

4. With the Static Water Level at 75'-0" below Ground Level, a "Starting Submergence" of less than 50% was available, which was just sufficient for test purposes The "Drop," however, was much greater than was anticipated and the small discharge of 4,000 gallons per hour was the most that could be obtained from the available "Working Submergence." Various means were adopted to try and increase the yield by pumping to a bigger "Drop," but owing to the shallow depth of the well this could not be done.

5. It was therefore decided to abandon the well, withdraw the Strainers, and do a fresh boring deep enough to give the required submergence, for a big "Drop." This could only be done with a Power Drilling Machine.

6. In May 1928 a "Star" Drilling Machine was available, and was sent to do this boring, which was carried down to a depth of 280'-0', through various beds of large boulders known to Drillers as "Nigger Heads" Such formations are perhaps the most difficult to get through with a straight hole. We were fortunate, however in having an expert oil driller who managed to get down with a straight hole to the depth required, in remarkably quick time.

7. The diagram appended shows the strata drilled through, location of screen and the probable distribution of the gravel shrouding. The

3. At that time the permanent pumping plant for this well had not been provided. Development was completed, and the yield test showed that 5,000 gallons per hour could be obtained from it with a drop of 20′-0″.

4. The 6′-0″ length of screen used was made up in the Railway Shops from an ordinary 6″ pipe, in which were milled 75 longitudinal slots each 4″ × ⅜″. The yield per square foot of screen used, works out at 550 gallons per hour.

5. The air lift *cum* centrifugal plant provided for this well was erected and was due to be tested on 25th April 1929.

6. After a short run the plant was shut down, and when restarted, it was found that sand had blown in and filled the well from the bottom, located at 214′-0″ below ground level, to the top of the screen at 74′-0″ below ground level, " freezing " the Air and Eduction Pipes in the well.

7. This came as a shock to us, and appeared to be a very serious set back for this type of well. As the permanent pumping plant had been supplied, something had to be done to provide a well from which this plant could pump water.

8. It was immediately decided to resort to the Laki Marwat method, which proved so successful there. The Air and Eduction pipes were [illegible] "Sludger." Six gravel [illegible] the top of the screen, as [illegible] filled with gravel to a [illegible] ork amounted to about Rs. 300.

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15. If this quantity has distributed itself uniformly around the 6'-0" length of 6" screen, there ought to be a 2'—0" ring of shrouding, and I am inclined to believe that this thickness of shrouding does in fact exist around the screen now, as the extremely fine sand in which the screen is located would have to be some distance from it, for the velocity of the water flowing through it to be below the "Critical Velocity."

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[illegible]

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7. The diagram appended shows the strata drilled through, location of screen and the probable distribution of the gravel shrouding. T[illegible]

strata in which the screen is placed was considered the most promising, as it was composed of large boulders and coarse sand. The screen was the same type as that used at Rohtak.

8. It was considered that gravel development from the surface would not be necessary, as, when pumping, the sand would be drawn through the 4" × ⅜" slots, and the smaller boulders would gradually pack around the screen, eventually keeping the sand out. Apparently [illegible] were so packed as to allow [illegible] well was pumped, but the [illegible] screen, with the result that [illegible] en the casing was drawn, allowed the sand in the strata above the screen, as far up as the red clay at 115'-0" to move down and through the screen.

9. After several hours pumping it was decided to plumb down along the outside of [illegible] that a clear openi [illegible] sanding continued, and [illegible]

10. As the casing pipes had been completely drawn, it was not possible to feed down gravel between the casing and the screen. The methods used at Laki Marwat and Rohtak suggested themselves, but were not adopted, as previous experience had proved that it was going [illegible] boring was done with a drilling machine.

11. It was therefore decided to try the effect of feeding gravel down the gap around the tube well. This was done and in five hours the 300 c ft., of gravel, which was available at the site, had all been used, and in plumbing down again the plumbob stopped at 80'-0".

12. It is impossible to suggest how this quantity of gravel has distributed itself around the tube well The fact remains that the sanding had ceased, although small quantities could still be drawn up when the well was "Back Blown." If it is assumed that a clear gap existed from the bottom of the well to the top, and that this 300 c. ft., of gravel distributed itself evenly around the well from 280'-0" to 80'-0", the depth of the shrouding would be about 4½". It is unlikely that the gap left when the casing was drawn, remained open below the screen from 170'-0" to 280'-0" during [illegible] t the time the gravel was fed do [illegible] ravel distributed itself from abo [illegible] a 8" ring around the well, between these levels.

13. Before completing this work some more gravel was obtained and fed around the well up to ground level, as it is possible when the well has been put into service, that as a result of continuous pumping, this gravel will work down towards the screen.

Tube Well at Lyallpur.

1. This well has an entirely different feature of interest, from that [illegible]

well was relatively large, and the well was pumped for several hours a day.

2. Prior to the installation of the Tube Well at Lyallpur, the Railway obtained its supply of water for Locomotive and drinking purposes from irrigation canals The drinking water was passed through a "Jewell" filter.

3. In October 1926 a boring was put down in the Station Yard with a view to substituting a Tube Well supply for the Canal supply.

4. As work progressed samples of water were taken at 110'-0", 159'-0", 210'-0" and 258'-0" below Ground Level, and sent for analysis to the Chemical Examiner to the Punjab Government, as to their suitability for Locomotive and drinking purposes.

5. The analysis showed that the quality of the water down to the 210'-0" level is more or less uniform, whereas below this level the quality rapidly deteriorates.

6. It was therefore concluded that it would be possible to obtain suitable and ample water, from the water yielding strata, by keeping the bottom of the Screen above the 210'-0" level and this was done by installing 120'-0" of "Ashford" Screen, between 86'-0" and 206'-0". The yield test of the completed well was carried out on 11th to 13th March 1927.

7. During the test another sample of water was taken and the following report was received from the Chemical Examiner :—

Results of Analysis Expressed in Parts per 100,000.

Water sample test.	Sample taken on 13th March 1927, during the test. "A".
Reaction	Alkaline.
Free Carbonic Acid ..	Slight.
Chlorides (as Nacl)	5·85 parts per 100,000.
Nitrates	Nil.
Nitrites	Nil.
Sulphuretted Hydrogen ..	Nil.
Lime	Slight.
Iron	Traces.
Sulphates	Moderate.
Total solids	100 parts per 100,000.
Hardness Clark's Scale. Total Hardness ..	3·5 Clark's
Hardness Clark's Scale. Temporary	3 "
Hardness Clark's Scale. Permanent	·5 "
Oxidisable matter	.. .. ..
Free Ammonia	·006 parts per 100,000.
Albuminoid ammonia ..	·004 parts per [illegible]
Opinion :—	Fit for drinking

This analysis agreed fairly closely with the average of the analyses of samples taken during the boring For purposes of ready comparison I have selected the more important heads.

	Na Cl.	Total Solids.	Total Hardness.	Temporary Hardness.	Permanent Hardness.
Sample at 110′	11 7	90	6	3·5	2·5
Sample at 159′	6·7	50	4 5	3	1·5
Sample at 210′	7·5	110	7	5	2
Total ..	25·7	250	17·5	11·5	6
Average ..	8·5	83	5·8	3·8	2
Sample during Test "A" ..	5·85	100	3·5	3	·5

8 As this report was satisfactory an Air Lift Cum Centrifugal Pumping Plant capable of delivering 25,000 gallons per hour was ordered for the well

9. For various reasons the plant was not erected till July 1928, and tested on the 7th August 1928 During the test another sample of water was taken and sent for analysis. It will be noted that this sample was taken 17 months after the last, when the yield test of the well was carried out [illegible] y been appointed to this Railway, and one of whose duties is to analyse samples of water as to their chemical suitability for Locomotive and drinking purposes.

The following is the report of his analysis :—

"B" REPORT ON THE SAMPLE OF WATER TAKEN ON 7TH AUGUST 1928.

	Parts per 100,000.
Chlorides (Cl)	4·4
Sulphates (SO_3)	6·4
Carbonates (CO_2)	21·5
Nitrates (N_2O_5)	Traces.
Lime (CaO)	2 9
Magnesia (MgO)	·5
Soda (Na_2O) plus other minor constituents, not determined ..	31·9
Total Soluble Minerals ..	67 6

Report :—

This works out approximately :—

Magnesium Carbonate	..	..	1·0
Calcium Carbonate	..	..	5·2
Calcium Sulphate	..	..	Nil
Sodium Carbonate	..	..	45·0
Sodium Sulphate	..	..	11·3
Sodium Chloride	..	..	7·3

Remarks :—

" Is a very alkaline water, and will be found to be highly corrosive to boilers. There is also some tendency to prime. I do not recommend this water if other is available."

11. This adverse report caused considerable disappointment as

ordering the permanent plant.

12. On a careful comparison of the analysis of samples "A" and "B" the former by the Chemical Examiner to the Punjab Government, and the latter by the North Western Railway Metallurgist, which are tabulated rather differently, it will be observed, that the Total Solids in sample "B" was lower than in sample "A", but the injurious constituent as reported in sample "B" was the high Sodium Carbonate content. This was not brought out in the Chemical Examiner's Report on sample "A."

13. What appeared to be a confirmation of the unsuitability of this water was brought to notice by the Divisional Superintendent in a report that drivers maintained that the Lyallpur Tube Well water was bad for their boilers.

14. Drivers are not in a position to state why any particular water is bad, but are able to appreciate the difference in the steaming results, after they have watered at a certain station, so that when persistent reports are received from them by Operating Officers that the water at a station is bad, investigations are started to establish the cause for these complaints.

15. It was found that the steaming troubles complained of were due to priming, caused by the mixture of Tube Well water from Lyallpur and canal water supplied from Gojra and Sangla Hill the next watering stations on either side of Lyallpur.

[illegible]

which would only be noticed by the Boiler Inspectors, on careful examination. The question to be decided was— should the Tube Well water be used for the period that would be required to develop corrosive action?

17. Reports received by the Divisional Officers, none of which [illegible] for this reason.

18. From a common sense point of view these reports seemed to be directly contrary to what one might expect. For over 30 years Lyallpur has been heavily irrigated with sweet water from the rivers, which undoubtedly are the main source of supply of the subsoil water.

19. From the section of the boring a copy of which is appended [illegible] flow of sweet water from the canals.

20. The points at which this sweet water is actually fed into the subsoil, to take the place of the chemically laden water, obviously cannot be defined, but it can be assumed that they are in the vicinity of the well. Although the quantity of water pumped out in a day is very small as compared to the storage capacity of the subsoil reservoir of water, a flow does in fact take place, which can only tend to sweeten the water, as replenishment is only taking place with sweet water.

21. It was therefore decided to keep this well in use, and every quarter, take a sample of water for analysis by our Metallurgist, to observe the changes in quality, if any, that were taking place.

22. Unfortunately, early in October 28, only two months after the [illegible] h the foundation. It was not [illegible] months later, on 22nd July 1929, another sample was sent for analysis. A further sample "C" was taken 3 months later, on 14th October 1929. The sample taken on 22nd July 1929 differed slightly from that taken on 7th August 1928.

23. The table below gives the details of the analysis of the sample "C" taken on 14th October 1929 as compared with "B," the analysis of the sample taken on 7th August 1928, the differences being shown as plus or minus in the adjoining columns :—

Lyallpur Water Test.	Samples taken on 7-8-28	Samples taken on 14-10-29.	Changes as compared with "B."
	"B".	"C".	
Chlorides ..	4·4	2·8	— 1·6
Carbonates ..	21·5	7·9	—13·6
Sulphates .	6·4	4·6	—1·8
Nitrates ..	traces	traces.	
Lime ..	2·9	3·4	+·5
Magnesia ..	·5	2·0	+1·5
Soda .	31·9	10·9	—21·0
Silica .	..	·4	+·4
Iron Oxide & Alumina .	..	·1	+·1
Total Soluble Minerals ..	67·6	32·1	—35·5
This works out (approximately) ..	.	..	..
Calcium Carbonate ..	5·2	6·1	+·9
Calcium Sulphate .	Nil	..	..
Magnesium Carbonate ..	1·0	4·2	+3·2
Magnesium Sulphate ..	..	..	..
Sodium Nitrate ..	..	..	..
Sodium Carbonate ..	45·0	7·2	—37·8
Sodium Sulphate ..	11·3	8·2	—3·1
Sodium Chloride ..	7·3	4·7	—2·6
Silica etc. .	..	·5	+ ·5
Remarks :— ..	It is very alkaline water and will be found to be highly corrosive to boilers. There is also some tendency to prime. I do not recommend this water if other is available.	Quite good. Probably safe to drink.	

24. [illegible]

25. The average pumping hours per day is only $6\frac{1}{2}$, which gives a total of 18,000,000 gallons, roughly 1,000 cusecs pumped from the well.

26. We shall continue to take further samples for analysis, every quarter, for the next year or two, and will be glad to forward the results to anyone interested in the subject.

27. I would like to point out that these analyses are done with the greatest care by the North Western Railway Metallurgist who is an authority on Boiler Feed Waters and is keenly interested in the quality of water supplied for our Locomotive Boilers. These analyses therefore can be taken as correct, but we have yet to establish that this improvement is not merely seasonal.

28. The last sample "C" was taken just after the rainy season, which was exceptionally heavy this year, and it is just possible that this may have influenced the quality of the water at the time.

29. The next two samples which will be taken in January and April should prove this.

Tube Well at Umballa Cantonment.

1. By far the most interesting and successful of the Gravel Developed Wells that have been installed on the N. W. Railway are two that have recently been completed at Umballa Cantonment.

2. Troubles, due to the inadequate supply of water at this station, have been experienced, I should think, for over 30 years.

3. I am informed that the N W Railway have since 1913 tried to increase the water-supply at Umballa by the use of Tube Wells. Prior to this date, whenever the shortage became acute, one more large open [illegible]

4. Apparently the D U. K. Railway experienced similar troubles with their water-supply at Umballa, and resorted to the same methods to tide them over their difficulties, for they have a battery of three open wells, also near the Tangri River. In one of these wells a tube well has been sunk.

Since the D. U. K. now belongs to the N. W. Railway, we have taken over their watering arrangements, so that we now possess at Umballa :—

1—25'-0" dia. open well.
1—25'-0" dia. open well.
2—16'-0" dia. open well.
4—12'-0" dia. open well.

These wells can only provide 12,250 gallons of water an hour, which is insufficient for our present requirements.

5. A brief account of the efforts made by other authorities to deal [illegible] ut of [illegible] the [illegible] ir as can be gauged at present, promise to be entirely successful

6 The peculiar difficulties of obtaining a ground water-supply at Umballa Cantonment are dealt with in a Report on "The Water-supply of Umballa City and Umballa Cantonment" by Mr. D A. Howell, A. M. I. C E., Executive Sanitary Engineer, Public Works Department, Punjab. Extracts from this report are quoted to indicate the reasons ascribed for the difficulties experienced, and the methods adopted to cope with them.

"The present Umballa City Water-supply Scheme from wells at "Handesra was carried out about 1895, and was designed to yield a "supply of 240,000 gallons per diem. The yield has now dropped "to about 80,000 to 90,000 gallons of water per diem, probably due to "clogging of the sandy strata round the well bottoms by clay particles "carried and deposited by the infiltration of water into the wells. It "should be noted that the decrease of yield of water above described has "taken place in spite of the fact that a considerable expenditure on [illegible] "the last 30 years.

"In 1921 about Rs. 66,000 was spent by Government in putting "down a tube well fitted with a vertical and horizontal strainer, and a "subsidiary pumping station, at Sarangpur, in Patiala State, on the "banks of the Tangri Nallah, in order to pump additional water to "Handesra. This has proved more or less a failure, as the yield which "was about 4,000 gallons per hour in the first instance dwindled within "12 months of starting pumping operations to less than 1,000 gallons "per hour at a depression head of 10 feet In 1923 an experimental "well 40 feet internal diameter was completed at Sarangpur at a cost of [illegible]

"The Bibyal wells have been gradually decreasing in yield due to "'choking' effect, and additional wells have been sunk from time to time; "the last, sunk in 1923, being two in number, each about 30 feet diameter, "and now ready to be pumped. The present systems for Umballa "Cantonments are quite inadequate to provide a proper water-supply "for the Cantonments."

7. [illegible] which the Military Works were [illegible] eport was written had only reache [illegible]

8. He also refers to a hand boring sunk in 1869-72 to a depth of [illegible]

means of extraction."

9. This statement sums up the crucial problem of the ground water-supply at Umballa Cantonment Water does exist in the belts of water bearing strata The question is, how is this water to be recovered. To my mind the only way is by the Air Made Gravel Well.

10. This solution only applies to relatively shallow wells, by which I mean, to wells located in the beds of water bearing sands which are encountered to a depth of about 250'-0", for two reasons:—

(*a*) Gravel development at depths below 250'-0" is expensive and rather uncertain

(*b*) At depths below 250'-0" and up to 600'-0", at Umballa Cantonment, there are sufficient beds of coarse sands *and gravels to obtain a* large yield, (up to 40,000 gallons per hour) with the ordinary fine slot screen as generally used in the Punjab.

11. Looking at the sections of the 701'-0" boring, referred to by Mr. Howell, and the 1,600'-0" boring sunk by the Military Works, it will be seen that the beds of sand and gravel encountered in these borings below 240'-0" are as follows:—

701'-0" BORING.

278-302 = 24'-0"	Sand with clay pebbles boulders.
335-376 = 41'-0"	Sand with some clay and kunkar.
394-424 = 30'-0"	Sand with some gravel, large stones and kunkars.
515-546 = 31'-0"	Coarse sand.
585-601 = 16'-0"	Sand fine with *boulders.*
142'-0"	

M. W. S BORING 1,600'-0"

240-0—270-0	= 30'-0"	Sand.
280-0—312-0	= 32'-0"	Gravel sand and boulders
333-0—345-0	= 15'-0"	Sand
386-0—395-0	= 9'-0"	Sand
445-0—465-0	= 20'-0"	Gravel and boulders.
480-0—498-0	= 18'-0"	Sand.
528-0—603-0	= 75'-0"	Coarse sand
	199"-0"	

In the former boring it would have been possible to instal 138'-0" of strainers, and in the latter 188'-0".

12 I have not heard definitely why the Military Works did not make use of these beds of water yielding sands, as they could easily have obtained an yield of 40,000 gallons per hour, (1,000,000 gallons per day for 24 hours pumping) with a ' Drop " of about 20'-0". This allows for an yield of 85 gallons per l. ft. of strainer, which is by no means the limiting yield of a fine slot strainer.

13. I was informed that the Engineers were expecting an Artesian Supply, and therefore discarded these beds of water bearing sands, and continued the boring down to 1,600'-0" in the hope of striking such a supply, which they did not.

14. Apparently Mr. Howell's conviction that a ground water-supply, either from Open Wells for Tube Wells, in the vicinity of Umballa, could not b. relied on to provide and maintain the yield required, decided him in carrying out investigations further afield.

15. These investigations led him to discover a plentiful supply of [illegible] U. K. [illegible] which [illegible] Umballa [illegible]

16. As the Railway were experiencing acute difficulties with their [illegible]

17. The Railway would have preferred to have their own independent supply, under their direct control, as their past experience of Joint

[illegible]

18. Early in 1926 the Railway started independent investigations in the Ghaggar-Chandigarh area, and the conclusions they arrived at agreed closely with those on which Mr. Howell's scheme were based. An agreement [illegible] Punjab Government at the end of [illegible] Joint Scheme, but for the fact that [illegible] on the Railway.

19. *During the period (1926-28) the investigations and negotiations* for this Joint Scheme were in progress, improvements had been effected in operating methods on the Railway, with the aid of the powerful locomotives that had been provided. These methods permit of the elimination of a number of engine changing stations, and concentrating on a few large sheds, with the result that Umballa Cantonment will very soon not have the large number of engines based there, that it now has, and consequently will require much less water. However, something had to be done quickly and inexpensively to provide the immediate needs of the station till these changes had been made

20. The Gravel Developed Well at Rohtak had just been completed successfully and it was decided to try a similar well at Umballa Cantonment. This proved a complete failure, and I have since come to the *conclusion that the reason for this failure was due to the very small* clearance between the casing pipes and tube well pipes, which was [illegible]

[illegible] In both these cases the gravel fed [illegible]

option but to try them out

21. For Air Developed Wells in the U. S. A. 30" and 24" casing is used for 12" and 10" wells, which gives a nett clearance of 8" to 6" for the gravel to move down. In our wells we were using 15" casing for 10" and 6" wells, which left a clearance of from 1½" to 3½".

22. I [illegible] and succeeded [illegible] st of Rs. 1,400 [illegible] only seven feet [illegible] The yield works out at 1,500 gallons per hour per square foot of screen, *which I believe is a record for a Tube Well in the Punjab, for a "Drop"* of 7'-0" only. The amount of gravel shrouding placed around the well was 272 c.ft. and the quantity of sand pumped out was 1,000 c.ft.

23. Encouraged by this success, orders were issued to make another attempt at a Gravel Developed Well, and an estimate for Rs. 11,000 was sanctioned for this work.

24. Before starting the Gravel Well, it was decided to establish the water yielding capacity of the strata, and with this in view, a " Pilot " Tube Well with 16'-0" of 10" " Ashford " Screen was installed between 38'-0" and 54'-0", in the only layer of sand available up to 145'-6", the depth bored. The well was tested for yield for 24 hours and delivered 3,110 gallons per hour with a Drop of 19'-9".

25. This result indicated that water was available in the stratum, and that it was being replenished as fast as it was being drawn out, as the " Drop " [illegible]

hours [illegible]

Well [illegible]

depth [illegible]

Lift Pump. The strata drilled through were similar to that in the " Pilot " well. A length of 6'-0" of 10" bore, large slot screen, was lowered and placed between 46'-0" and 52'-0" The casing pipes used were 13" bore, allowing a nett clearance of about 1½" between the well and the casing. This small clearance ruled out the American method of feeding down gravel between the casing and well pipes, and the only other way to attempt gravel development was by means of tubes sunk around the well.

[illegible] ons per hour with a " Drop " [illegible]

27. This well showed that outside development was a suitable way of getting over the difficulty with small casing pipes and in sufficient

clearance, and as far as India is concerned, is, I believe, a cheaper and more practicable method, as large casing pipes would require machine drilling, with the consequent heavy outlay in plant and machinery. [illegible]

Those sunk at Umballa Cantonment took two days each and cost Rs. 190 to sink the nine that were used.

28. As there was sufficient money saved from the sanctioned estimate of Rs. 11,000 a second Gravel Developed well was sunk 158'-0" from the "Pilot" well and 168'-0" from No. 2.

29. The same length and size of screen was used, and the strata drilled through differed only slightly from the other two wells. The only change made was in the location of the gravel tubes. In No. 2 well it was found that the majority of the gravel that moved down to the screen was from the tubes placed at a 1'-6" radius from the well. It was therefore [illegible] from [illegible] width [illegible] yield

30 In this we were entirely mistaken, as was found when the screen was exposed for a few inches, and pumping for the development started. Enormous quantities of sand were pumped out but no gravel worked down the tubes, with the result that in half an hour serious cavitation occurred, almost completely blocking the screen with the clay and ashes which had fallen in from above. Pumping was stopped and we appeared to be faced with a complete failure. The cause of the trouble was quite apparent, and was due to the gravel tubes being located too far from the well for the initial stages of development. Instead of the sand moving towards the slots in the screen at an angle, as we believed it would, and so allow of the gravel in the tubes, 3'-6" away, being drawn down and around the screen, the sand pumped out apparently left a 2'-6" cylindrical gap all around the screen into which the upper strata of clay and ashes fell.

31 [illegible] anticipated. The clay and ashes were washed out and gravel moved down

the tubes to replace them. By frequent "Back Blowing" and pumping for about 240 hours the well now delivers 9,070 gallons per hour of clear water practically free of all traces of sand, with a "Drop" of 24'-3". This is not as good as well No 2 but when one considers that as a result of the serious cavitation, the screen was completely choked at one time, the result must be considered as satisfactory, particularly as the "Drop" is steadily getting less for the sam[illegible] channels for the flow of water are [illegible] the "Drop" has decreased fron [illegible] appe ided which gives all the details connected with the "Pilot" Well and Gravel Developed Wells Nos. 2 and 3

32 The points which it is desired to emphasize are.—

(a) The low cost of a Gravel Developed Well as compared with the fine slot tube well of equal yield and "Drop" The cost of the well at Kurk hetra installed in October 28 with fine slot "Tej" Screen was Rs. 5,800 against Rs. 3,500 for Well No. 2.

(b) The scope of the Gravel Well These can be used in shallow beds of sand where the fine slot screen would be of little or no use. In the case of Umballa Cantonment 16'-0" of Ashford Screen yielded 3,110 gallons per hour with a "Drop" of 19'-9" against 11,170 gallons per hour with a "Drop" of 20'-0" from Gravel No. 2 located 36'-0" from the Ashford Well.

(c) The troubles encountered with clotting of screen opening is not likely to be experienced with the wide slot screen, as the width of these openings are about $\frac{400}{1,000}$ against $\frac{12}{1,000}$ for the "Ashford" and "Tej" Screens.

(d) The "Drop" in a Gravel Developed Well is far less likely to increase than in a fine slot one, as the finer sands are continually being drawn into the well and pumped out, opening up fresh supply channels to the well.

33. With the experience we have had so far with the installation of Gravel Developed wells, I would recommend the use of separate gravel tubes which should be of the largest possible bore The number of tubes used should not be less than six and they should be arranged as in the sketches appended. Obviously better results may be expected if the number of gravel tubes could be increased to 9 or 12, but this would of course increase the cost of the well

Tube Well.	No. 1 " Pilot".	No. 2 Developed.	No. 3 Developed.
Depth of Tube ..	91'-3"	130'-0"	146'-6"
Dia. of plain pipe ..	10"	10"	10"
Dia. and type of Screen	10" Ashford.	10" Large Slotted.	10" Large slotted.
Length of Screen ..	16'-0"	6'-0"	6'-0"
Location of Screen ..	38'-0" to 54 -0"	46'-0" to 52'-0"	47'-2" to 53'-4"
Size number of gravel tubes ..	..	Nos. 9 8" Tubes	Nos. 9 8' Tubes. Nos. 4 13' Tubes
Distance from Tube Well ..	..	Nos. 3 at 1'-6" Nos. 6 at 7'-0"	Nos. 9 at 3'-6" Nos. 4 at 6"
Static Water Level ..	25'-3"	25'-0"	25'-3"
Discharge when Screen was totally exposed	3,110 gallons per hour.	9,070 gallons per hour	4,910 gallons per hour.
Drop when Screen was totally exposed ..	19'-9"	20'-0"	30'-0"
Discharge when developed ..	..	11,170 gallons per hour.	9,070 gallons per hour.
Drop when developed ..	..	20'-0"	24'-3"
Discharge per sq. ft. area of Screen ..	74	740	600
Sand pumped out ..	..	417 c.ft.	1,807 c.ft.
Gravel poured in .	..	62 c.ft.	118 c.ft.
Number of pumping hours to develope ..	..	132 hours.	240 hours.
Number of pumping hours after development ..	..	246 hours.	66 hours (This well is still being pumped).
Effect on Tube Well when others are being , umped ..	None.	None.	Not observed.
Cavitat on ..	..	A little	A vast amount.
Cost of terial ..	Rs. 910	Rs. 1,900	Rs. 1,800
Cost of bour ..	Rs. 630	Rs. 1,600	Rs. 2,700
Total cos ..	Rs. 1,540	Rs. 3,500	Rs. 4,500

DISCUSSION.

The Author introduced his paper and said his intention in submitting the paper was to indicate the progress that had been made on the N. W. Railway in obtaining a suitable and adequate supply of water from Tube Wells in places where it had been previously decided that a Tube Well supply could not be obtained.

This had been rendered possible by the introduction of modifications in the type of Tube Wells hitherto used in the Punjab, as the result of the study of methods adopted in other countries where conditions were similar to those here.

Most of the wells described in the paper were of the Gravel Developed Type with large Slot Screens, and further experience with them strengthened his conviction that this type would solve many of the cases where troubles were experienced in the past with Tube Wells due to choking

On the N. W. Railway they invariably had to provide a combined locomotive and drinking water supply and therefore could not make use of the first bed of water-yielding-sand encountered due to the surface water being liable to bacteriological contamination. They were therefore compelled to draw their supplies from the deeper beds of sand, thus increasing the cost of every item connected with the well *viz*, plant, drilling, plain pipes and development.

Where the tube well was not required to provide drinking water, and was only used for irrigation or for dewatering the soil, the first bed of water bearing sand could be used.

Such a well would seldom need to be deeper than 50′-0″ and from the yield per S. ft. of screen given in the paper it was easy to estimate that for the same discharge a Large Slot Screen Well would cost only a small fraction of what a fine slot screen well cost He ventured to suggest this ty [illegible] authorities in [illegible] required were [illegible] any workshop.

With the advent of cheap electric power and the adoption of a cheap and nonclogging type of the Well such as the Large Slot gravel developed type promised to be, there was reason to believe that tube well irrigation would usefully supplement canal irrigation.

He pointed out an error that had been made in Paras 15 and 16 Pages 161 and 162. The tests that were carried out and described in the paper were made in connection with the Tube Well at Tandlianwala not at Lyallpur as mentioned.

Mr D. A. Howell said he was particularly interested in Mr. Vardon's paper as the author had quoted at considerable length from the speaker's "Report on the water supply of Ambala City and Contonments." The [illegible] been proved in many wells, [illegible] two deep borings, one put [illegible] ago and another to a depth [illegible]

The strata in both of these deep bores consisted of bands of clays and sands. The sands generally were rather fine and contained an admixture of fine clay.

The Ambala waterworks Headworks which were built about 34 years ago near Handesra, about 8 miles north of Ambala consisted of shallow percolation wells. The yield of these wells had diminished enormously and today the wells yielded only about 33 per cent. or less as compared with their original yield. The same phenomenon had been observed in the case of the Ambala conto[illegible] and also in the case of a 40 [illegible] near Sarngpur on the bank [illegible] the later care great case had been taken to ensure that overpumping did not occur Similar experience at the old Delhi water works had caused the abandonment of the percolation well System there and at Delhi drawn now the supply was from the River Jumna.

The cause of the reduction of yield, he considered to be due to clogging of the pores of the sand strata round the wells due to the draw on the wells, by clay particles carried by the flow of water towards the wells.

Mr Vardon had shown that he had achieved a certain measure of success with the gravel developed tube well but this did not prove that the final solution of the problem was in sight and the speaker considered that it was a grave risk to rely on gravel developed tube wells as a source of supply for a permanent watersupply scheme to deal with Ambala Contonments and Ambala City, with a population of about 70,000.

Possible there were cases where no other supply might be available and under such circumstances admittedly there would be no alternative except to experiment with different forms of tubewells, if that were possible.

About 17 or 18 miles north of Ambala there appeared to be an extensive boulder formation at the base of the Siwalik (Tertiary) Foot hills. Due to the flattening out of the slope of the alluvial formation as it left the foot hills, the subsoil water surface reached the surface of the ground near the southern edge of this formation just north of Chugger Station on the Ambala Kalka Railway.

The formation contained large quantities of water and the level at he point where the water line coincided with the surface was about 100 eet ab

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The au

ıad said "

upplied fr

mprove in quality when pumped regularly for some months" This ırgument, however was based on the results of a single tubewell and it eemed dangerous to make a general case out, simply on the result of ıne particular example.

The auth '6 paragraph 192, had stated that he saw ere were appreciable Variations on the Railway tubewell at Lyallpur.

This conclusion was entirely at variance with the speaker's own experience of large numbers of tubewells sunk in the Punjab. He had found hat generally the stratefication of the sands and clays of the alluvium vere difinitely centricular in shape and almost everywhere there were considerable differences between the cross sections of boring placed at comparatively short intervals apart.

The speaker referred to paragraph 20 page 162 on which the Author ıad said that the point at which sweet water was actually fed into the suboil could be assumed to be in the vicinity of the tubewell. In this he mphatically disagreed with the Author as in spite of the centicular formaions of the alluvium, it was certain that these layers were interconnectd longitudinally or horizontally in many directions and there seemed o be no reason why replenishment of any particular sand strata could ıot take place from considerable distances horizontally.

R. B. Amar Nath Nanda said that he wished to speak on a few oints raised in Mr. Vardon's paper, because they in the Public Health Circle had been working in the direction of tube well supplies for large ırban areas in the Punjab for 15, on 20 years.

Mr. Vardon had in his paper dealt with a few tube wells which had een sunk by him for the N. W. Railway say at Laki Marwat, Rohtak, Cambellpur, Lyallpur and Ambala Cantonment. Rohtak and Ambala vere important centres of urban population of the Punjab and they were leeply interested in the water supply problem for these places and any olution that might be offered by engineers in this behalf.

He further said that the question of Ambala water supply had been ngaging their serious attention since 1895. Briefly recapitulating the fforts made here from time to time he stated that the Ambala water

supply was derived from a distance of
taken the shape of 27 percolation we
a discharge of 2 lakh gallons origin

reached the exhaustion point or the choking effect of fine clay particules had proceeded to such an extent in the water bearing subsoil strata surrounding these wells, that the yield had diminished considerably. Another effort they made here was with a 40 ft. diameter well which had been sunk about 20 ft. below spring level on the bank of the river Tangri in 1923. This well originally gave a discharge of 1 lakh gallons in 16 hours pumping and under 4 ft. head of depression. Extreme care was

experimenting with these forms of tube wells only for the last few years had solved the problem of Ambala water-supply by drawing upon the same unpropitious subsoil

The only explanation given in the paper was that the subsoil water at Ambala had been coaxed out of the ground He said this was tantamount to making a regular raid in to the subsoil. Now this coaxing process could not last long, because although a tube well as a form of withdrawl of water from the subsoil had an advantage over a percolation well in that it had its vertical strainer surface exposed to the inflow of the horizontal stream-lets along their natural lines of flow between layers of sand, still the output effect, or the 'net' performance was limited by the limited quantity of water contained in this finely combed subsoil basin of Ambala. The difference between Mr. Vardon's tube wells and theirs was that they had to supply drinking water for urban areas where no risk could be run whereas he had to provide for the locomotives, and if his supply failed eventually in one place he could shift his watering arrangements to another centre

He described the case of Pasrur for instance where they had to sink tube wells both for the supply of the town and the Intermediate College that had been recently opened here. In 1916, the P. W. D. had sunk a

supply for his College when the railway had solved it for their locomotives

only a 100 yards away That was how these new ideas were putting them to trouble and it was for this reason that he had taken this attitude in dealing with this paper, otherwise he would welcome this type of gravel fed screen well if it was found to stand the test of time and gave eventually what it promised to give in the beginning.

Colonel Battye wanted to know whether the Springs that Mr. Howell referred to in the Siwaliks were in British territory : if not in British Territory there was some prospect of their remaining permanent : otherwise there was every prospect of their drying up in the course of time as the denudation of the Siwaliks continued. This was rather an interesting sidelight on the importance of Mr. Glover's paper.

He then referred to the question of afforestation and its affect on the subsoil water throughout the submontane district. He said that the Enquiry Committee on the Hydro-electric project had been very impressed with the great possibilities of a market for power from tube wells and had asked them in conjunction with the Agriculture and other Departments to investigate this The prospect of these tube wells being a success however, depended upon the maintenance of the subsoil water beds the submontane districts, which again depended upon afforestation.

Turning now to the questions raised in Mr. Vardon's paper, he pointed out that this opened up a fresh view of the time—old controversy between the fine and the coarse screen. It seemed to him that Mr. Vardon's proposal constituted the equivalent of a filter with an [illegible]

a gravel filter seemed to point logically to the adoption of a coarse screen in conjunction therewith. Mr Vardon's use of filter really had [illegible] of the well from 12" to 12' and [illegible] the velocities at the outer edge [illegible] small enough to prevent the transportation of sand particles. Judged from this point of view it seemed that he was working on the right lines and that all tube wells in future would be based upon the employment of a gravel filter of this type.

Turning to the diagrams at the end of Mr. Vardon's paper, if this aspect of the question was correct, it would appear to be logical to adopt the concentric system of gravel tubes and to differentiate between the size of gravel to be inserted in each tube. For example, coarse

gravel should be put in to those adjacent to the main water tube and finer gravels inserted in to those nearer the circumference. He asked if any experiments had been carried out definitely on these lines.

Mr. Carl King said that the questions discussed really turned on the merits and disadvantages of the course screen tube well as against the fine screen tube well. In America at first fine screen tubewells such as those at present mostly installed in the Punjab were generally used. Later however as the result of experimental work, coarse screen tube wells had been developed and to-day this type had largely displaced the fine screen type. The subsoil conditions in the Punjab varied somewhat from those in some places in America where coarse screened tube wells were installed. Mr. Vardon had done very valuable work in showing that gravel developed tube wells could be successfully used and he hoped that his work would continue.

Mr [illegible]
for [illegible]
trib [illegible]
tance every year to India. He would suggest that a committee be formed of officers in Lahore of all Departments which were experimenting with tube wells, and that such committee should meet not less than once in 3 months to pool and record the information obtained, and for mutual discussion of methods.

In paragraph [illegible]
almost essential [illegible]
If the total suctic [illegible]
trifugal pump, the later was a much more efficient machine than an air lift pump, and much cheaper to instal. Occasional and would do no harm to such a pump, as the clearance or wear allowable in a centrifugal was considerable before efficiency is seriously affected.

If heavy sanding was anticipated during the first few days or weeks it should be possible to keep a special old pump for this work, to be replaced by a new one when the well had reached stable conditions.

Where there was a seasonal variation of water level in the tube [illegible] below
[illegible]
The cost of excavation and building to low levels was comparatively small (the outside of the pump house should be water-proofed with good cement rendering) and by this means the pump would be self priming at high levels in the tube well, while it was possible thus to deal with a much greater depression of head (as much as 20 feet below the centre of the pump). A good plan was to electric weld the joints in the suction pipe to avoid all possibility of air leaks.

A double advantage of such a system was that with one tube well, duplicate pumping plant [illegible]
[illegible]
[illegible]
of supply in the event of a breakdown or repairs to pump or power unit.

The accompanying sketch shewed such a plant as installed for the potable water supply of the Barrage Township at Sukkur. It had never given a moments trouble in the past three years

A disadvantage of deep well pumps was that in the event of a breakdown in the plant, the water supply must be stopped during repairs, or at the best, during the removal of the defective pump and its replacement by a duplicate plant kept ready

If it was desired to avoid such stoppages it was necessary to have a duplicate tube well, in addition to duplicate plant and this was not only expensive, but unless the wells were worked in rotation, the spare well was liable to be found choked or full or sour water when suddenly needed **Paragraphs 10 and 14 Page 156.** The gravel pipes might be jarred from above in order to shake down the gravel, but a better plan would be to put down a centrel agitating rod about $\frac{3}{4}''$ diameter with some cross pins, before the gravel was filled in. This rod could be turned from the surface as the gravel was filled in and would shake the gravel down. It would also probably help if the bottom of the gravel pipe was made slightly bell-mouthed for a foot or so as the jamming probably occurred at the bottom of the pipe, where the soil had worked up into the gravel before movement started.

The attached sketch illustrated the suggestions.

Mr. Vardon replying to the discussion said he was sorry to hear from Mr. Nanda [illegible]
N. W. Railway ca[illegible]
P. W. D., but he [illegible]
of worry to them. He said most of the comparisons in connection with the Ambala watersupply had been made between the ordinary open well, and gravel developed wells. He contended however that what applied to open wells was not equally applicable to a large slot tubewell.
[illegible]
and the drop had decreased and that the reason was that the finer sand particles were drawn through the screen and pumped out, and so opened out fresh channels for the flow of water into the well.

He said if anybody was interested in the records of the Ambala wells, he [illegible]
If the ope[illegible]
been caus[illegible]
choking must necessarily occur in gravel devloped large slot screen where the infiltrations conditions were entirely different.

The other point was that they had met their present requirements at a total cost of under Rs. 10,000 from gravel developed tube wells, whereas if they were to participate in the joint gravity scheme, they would have to incur an outlay of 10 lacs of rupees, which they could not afford. He was very much impressed with the possibilities of gravel developed wells and said that they had found another site right at Amballa Cant. statio [illegible] well. [illegible] n the Milit [illegible] well would be tried. [illegible]

[illegible] heavily irrigated territory round about, and also he meant that no big variation in strata took place He meant that there was a certain amount of continuity in the sand beds, they might not be horizontal or at any well defined angles, but connected to the main source of supply, which were the canals and therefore, were being sweetened with sweet canal water, gradually washing out the impurities of the subsoil through which it flowed into the well.

He noted that the Chairman was very very suspicious about these large slot screen wells He wanted to point out as Mr. King did that such wells had been tried out for many years in Texas and other States in the U. S. A., where large sums of money had been spent on other types without success He said that the authorities where such wells had been sunk were so impressed with steady maintenance of discharge that in many cases it had been decided to put in more. It was new to India [illegible]

[illegible] gravel well at Gujranwala. He had pumped out 1,500 cubic feet of sand and could not get the gravel to move.

As regards Mr. Musto's question, why they had concentrated on the air lift pump, he said that they had used a considerable number of these on the Railway, but they had not restricted themselves only to this type; they had quite a large number of other types of pumps as well.

PAPER No. 140

EXPONENTIAL LAW OF SUBSOIL FLOW.

By

Dr. N. K. Bose, M. Sc., Ph. D.

1. Experiments on the Shahpur Minor, Gujranwala and Ferozepore.
2. Deductions from the results—Exponential Law and Extension of this law into a General Law.
3. Application of this law to deduce a generalised form of Darcey's Law—which holds only on the surface—as such the new law is more general.
4. Application of this law to find out the transmission constant of soils.

Early in 1928 a series of experiments with tube wells were started on he Shahpur *Minor at Gujranwala and at Ferozepore. The object of* he experiments on the Shahpur Minor was primarily to study the beavior of the subsoil water-table during and after pumping from the tube ells and incidentally to find out its radius of influence. Ferozepore xperimental pumping was taken in hand to observe the effect of such umping on the subsoil water-table and to calculate the direction and ansmission constant of flow.

[illegible] These tube wells were worked by [illegible] Nos. 1, 2 and 3 of the water-table [illegible] the contours are for three separate eriods, before the pumping, during pumping and after pumping. In [illegible], the general [illegible] in the pre-pumping period, late No. [illegible] he pumping period, plate o. 2 ther [illegible] contour lines have been rned back near the tube-wells by the effect of the pumping and in the ter-pumping period plate No. 3 this depression still persists though umping had stopped for about six months. The effect of pumping [illegible]

[illegible]

ave been drawn from the subsoil water-table itself.

Ferozepore Tube wells.—Plate 4 shows an arrangement of the Ferozepore tube wells. The data relate to the tube wells A, B. . . . The wells marked F. F′, E E′, H H′, I I′, J J′, K K′, are for fresh experiments. These tube wells were worked by centrifugal pumps; and it has been found that the direction of subsoil flow turns through 30° from its normal direction of steady flow, as soon as pumping is started.

The experiments consist mainly in taking the undisturbed subsoil water-level before any pumping was undertaken. This is denoted by H (*see* Appendix I).

Then as pumping was started, the heights of the water-table at different distances from the pumps were noted till a steady cone of

the water-table obtained the steady level.

From these experiments it has been possible to deduce an Exponential Law of subsoil Flow which it has been found holds more generally than Darcey's Law, *viz*:

$$v = K \frac{h}{l}$$

lic-head bet-
these points
on constant.

holds only on the surface of the
n to its applicability to general
ove this limitation and to find out
a law which would be more generally applicable that the tube well data were examined.

The water-levels for each pipe were tabulated as shown in appendix and the quantity $\log \frac{H - Z_o}{H - Z}$ was calculated assuming for Z_o the
t $t - t_o$ and
a series of

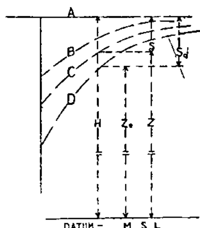
$$\log_e \frac{H - Z}{H - Z_o} = -\lambda (t - t_o) \qquad \text{(i)}$$

Now if $H - Z_o = s_o$ and

$H - Z = s$

we get $s = s_o e^{-\lambda (t - t_o)}$ (ii)

where s and s_o are the depths of the water profile, (or as usually understood the draw down curve) from the equilibrium level of the subsoil water at times t and t_o.



The curves A, B, C, D . . . give the profiles of the subsoil water-table at different periods; A is the steady natural water surface; D at time t_o. C at t and so on.

$$AD = H\text{-}Zo = s_o$$

$$AC = H\text{-}Z = s$$

The above relation (i) or (ii), it will be seen, holds generally for all the tube wells at the Shahpur Minor as well as at Ferozepore, and for all observation pipes irrespective of their distance from the pumps. Of course the factor λ is different for the experiments at the Shahpur Minor and at Ferozepore. This is what we should expect. This factor λ will be shown later to be a function of K the transmission constant of the soil (see equation ix).

[illegible]

relation.

Before an[illegible]
substitution wi[illegible]
cally the flow [illegible]
a very viscuou[illegible]
correctness of the deduction drawn from it.

The heights of water found in the observation pipes record the hydraulic pressures at the points in the soil at which the strainer points end. Hence though they might not record the actual watertable this being the case at Gujranwala where the watertable is in a clay layer—they record Hydraulic-Pressure-Head at the points which has been shown in a memoir of the Irrigation Research Laboratory equivalent to ϕ. As the observation pipes tap different points in the soil, this experimental relation holds for all points in the fluid. So that we get universally for the fluid medium.

$$\phi = \phi_0 e^{-\lambda(t - t_0)} \quad .. \quad (3)$$

The stream function ψ which is a conjugate function to ϕ will therefore satisfy

$$\psi = \psi_0 e^{-\lambda(t - t_0)} \quad .. \quad (4)$$

Before we proceed any further it will be well if the two quantities and ψ were defined more fully. Hydrodynamically we have the following relations between the velocities u, v, w and ϕ

$$u = -\frac{\delta\phi}{\delta x} = -\frac{\delta\phi_0}{\delta x} e^{-\lambda(t-t_0)} = -u_0 e^{-\lambda(t-t_0)} \quad (5)$$

$$v = -\frac{\delta\phi}{\delta y} = -v_0 e^{-\lambda(t-t_0)} \quad .. \quad (6)$$

$$w = -\frac{\delta\phi}{\delta z} = -w_0 e^{-\lambda(t-t_0)} \quad .. \quad (7)$$

Accordingly u, v, w the velocity components along the three axes will also vary as $e^{-\lambda(t-t_0)}$.

The direction of flow at any point on the surface ϕ = constant will always tend to be perpendicular to the surface. These lines of flow—orthogonal to the ϕ lines—are known as ψ lines.

Thus we have the two curves ϕ and ψ cutting each other at right angles.

In the case of subsoil flow it will be seen that ϕ curves are identical with the curves of equal hydraulic-head.

Stokes equations of Motion of viscous fluid are the following:—

$$\frac{\delta u}{\delta t} + u\frac{\delta u}{\delta x} + v\frac{\delta u}{\delta y} + w\frac{\delta u}{\delta z} = X - \frac{1}{\rho}\frac{\delta p}{\delta x} + \nu\nabla^2 u \quad ..(8)$$

$$\frac{\delta v}{\delta t} + u\frac{\delta v}{\delta x} + v\frac{\delta v}{\delta y} + w\frac{\delta v}{\delta z} = Y - \frac{1}{\rho}\frac{\delta p}{\delta y} + \nu\nabla^2 v \quad ..(9)$$

$$\frac{\delta w}{\delta t} + u\frac{\delta w}{\delta x} + v\frac{\delta w}{\delta y} + w\frac{\delta w}{\delta z} = Z - \frac{1}{\rho}\frac{\delta p}{\delta z} + \nu\nabla^2 w \quad ..(10)$$

$$\text{and } \frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} + \frac{\delta w}{\delta z} = 0. \quad ..(11)$$

is the equation of continuity, where $\nu = \frac{\mu}{\rho}$ is known as kinematic viscosity,

When the motion is very small, so that the inertia terms $u\frac{\delta u}{\delta x}$ *etc.*, can be neglected and the external force is only gravity we have,

$$X = Y = O, \text{ and } Z = g$$

and the above equations (8) (9) and (10) reduce to

$$\frac{1}{\nu}\frac{\delta u}{\delta t} = -\frac{1}{\mu}\frac{\delta p}{\delta x} + \nabla^2 u \quad ..(12)$$

$$\frac{1}{\nu}\frac{\delta v}{\delta t} = -\frac{1}{\mu}\frac{\delta p}{\delta y} + \nabla^2 v \quad ..(13)$$

$$\frac{1}{\nu}\frac{\delta w}{\delta t} = \frac{g}{\nu} - \frac{1}{\mu}\frac{\delta p}{\delta z} + \nabla^2 w \quad ..(14)$$

The above equations can also be written in the following form :—

$$\frac{1}{\nu}\frac{\delta u}{\delta t} = -\frac{1}{\mu}\frac{\delta}{\delta x}(p - g\rho z) + \nabla^2 u \quad ..(15)$$

$$\frac{1}{\nu}\frac{\delta u}{\delta t} = -\frac{1}{\mu}\frac{\delta}{\delta y}(p - g\rho z) + \nabla^2 v \quad ..(16)$$

$$\frac{1}{\nu}\frac{\delta w}{\delta t} = -\frac{1}{\mu}\frac{\delta}{\delta z}(p - g\rho z) + \nabla^2 w \quad ..(17)$$

because $(g\rho z)$ being a constant quantity with respect to x and y, $\frac{\delta}{\delta x}(g\rho z)$ and $\frac{\delta}{\delta y}(g\rho z)$ vanish and $\frac{\delta}{\delta z}(g\rho z)$ reduces to $g\rho$.

Now from equation (5)

$$u = u_0 e^{-\lambda(t - t_o)}$$

$$\frac{\delta u}{\delta t} = -\lambda u_0 e^{-\lambda(t - t_o)} = -\lambda u \quad ..(18)$$

Substituting this in (15) we get.

$$-\frac{\lambda}{\nu} u = -\frac{1}{\mu}\frac{\delta}{\delta x}(p - g\rho z) + \nabla^2 u$$

$$(\nabla^2 + a^2)u = \frac{1}{\mu}\frac{\delta}{\delta x}(p - g\rho z) \quad (19)$$

where $a^2 = \frac{\lambda}{\nu}$.

Similarly we get

$$(\nabla^2 + a^2)\, v = \frac{1}{\mu} \frac{\delta}{\delta y}(p - g\rho z) \quad .. \quad (20)$$

$$(\nabla^2 + a^2)\, w = \frac{1}{\mu} \frac{\delta}{\delta z}(p - g\rho z) \quad .. \quad (21)$$

Now differentiating (19) (20) and (21) with respect to x, y and z respectively we get

$$(\nabla^2 + a^2) \frac{\delta u}{\delta x} = \frac{1}{\mu} \frac{\delta^2}{\delta x^2}(p - g\rho z)$$

$$(\nabla^2 + a^2) \frac{\delta v}{\delta y} = \frac{1}{\mu} \frac{\delta^2}{\delta y^2}(p - g\rho z)$$

$$(\nabla^2 + a^2) \frac{\delta w}{\delta z} = \frac{1}{\mu} \frac{\delta^2}{\delta z^2}(p - g\rho z)$$

Adding these we get

$$(\nabla^2 + a^2) \left(\frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} + \frac{\delta w}{\delta z}\right) = \frac{1}{\mu} \nabla^2 (p - g\rho z)$$

Now from equation (11) we have, for continuity,

$$\frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} + \frac{\delta w}{\delta z} = 0$$

so that $\nabla^2 (p - g\rho z) = 0$ .. (22)

Now $u = \frac{1}{a^2\mu} \frac{\delta}{\delta x}(p - g\rho z)$

is a particular solution of (19) for, by substituting this in the latter we have

$$(\nabla^2 + a^2) \frac{1}{a^2\mu} \frac{\delta}{\delta x}(p - g\rho z) = \frac{1}{\mu}(p - g\rho z)$$

$$\text{or } \frac{1}{a^2\mu} \frac{\delta}{\delta x} \cdot \nabla^2 (p - g\rho z) + \frac{1}{\mu} \frac{\delta}{\delta x}(p - g\rho z) = \frac{1}{\mu} \frac{\delta}{\delta x}(p - g\rho z)$$

which is an identity by (22) Thus we get as a particular solutions of the differential Equations (19) (20) and (21)

$$u = \frac{1}{a^2\mu} \frac{\delta}{\delta x}(p - g\rho z) \quad .. \quad (23)$$

$$v = \frac{1}{a^2\mu} \frac{\delta}{\delta y}(p - g\rho z) \quad .. \quad (24)$$

$$w = \frac{1}{a^2\mu} \frac{\delta}{\delta z}(p - g\rho z) \quad .. \quad (25)$$

These expressions give the most general formulae for subsoil velocities.

The differential form of Darcy's law

$$u = K \frac{\partial h}{\partial x}$$

can easily be deduced from these. On the free surface we have p = cons. so that from (23) we get

$$u = \frac{1}{a^2\mu} \frac{\partial}{\delta z} (- g \rho z)$$

$$= - \frac{g\rho}{a^2\mu} \quad \frac{\delta z}{x}$$

$$= - k \frac{\delta z}{\partial x}$$

Thus Darcy's Law holds only on the free surface and confines itself only to the horizontal components of the subsoil velocity.

In conclusion the paper may be summed up with the following remarks. It is the **Exponential law**

$$s = so\ e^{-\lambda (t - t_o)}.$$

which is really the **fundamental equation** in subsoil hydraulics; all other relations such as the above equations (23) (24) and (25) or the Darcy's relation can be deduced from it mathematically.

APPENDIX.

These data are collected from measurement of water-levels after pumping had been stopped. Those water-levels (z) have been generally considered that were observed after sometime had elapsed since the pumps were stopped, as it was found that the water-level records were rather very irregular just after the cessation of pumping. The height of the natural water-surface, H, was taken that steady value of the water-surface which was observed just before pumping started or about a fortnight after it stopped, if they agreed among themselves, but if they varied very much the latter data only was considered. It was found that they differed when there was a general upward tendency of the water-level before the pumping started.

Well levels on the Shahpur Minor Gujranwala Tube Well A. 2-29.

H = 734·95 feet.

Date.	Interval since pumping ceased.	Time.	Z	H—Z	$\log_{10}(H-Z)$	$\log\frac{H-Z}{H-Z_0}$
2-2-29 .	3 hours	8 p.m.	734·0	0·95	—·022	
3-2-29 .	15 „	8 a.m.	734·25	0·70	—·155	—·133
3-2-29 .	27 „	8 p.m.	734·45	0·50	—·301	—·279
4-2-29 ..	39 „	8 a.m.	734·57	0·38	—·420	—·398
4-2-29 ..	51 „	8 p.m.	734·65	0·30	—·523	—·501
5-2-29 ..	63 „	8 a.m.	734·73	0·22	—·658	—·636
5-2-29 ..	75 „	8 p.m.	734·78	0·17	—·770	—·748
6-2-29 ..	87 „	8 a.m.	734·83	0·12	—·921	—·899
6-2-29 ..	99 „	8 p.m.	734·87	0·08	—1·097	—1·075

$$\frac{H-Z}{H-Z_0} = e^{-\lambda(t-t_0)}$$

$$\log_e \frac{H-Z}{H-Z_0} = -\lambda(t-t_0)$$

$$\lambda = \frac{\log_e \frac{H-Z}{H-Z_0}}{t-t_0} = \frac{\log_{10}\frac{H-Z}{H-Z_0}}{(t-t_0)\times \cdot 43}$$

from plate No. 5. $= \frac{\cdot 8^*}{74 \times \cdot 43} = \cdot 025$ where unit of time is hour.

$= \cdot 7 \times 10^{-5}$ in F. G. S. units.

**Note.*—0·8 is taken off the curve A 2 29 Gujranwala, $t-t_0 = 74$, λ is obviously the slope of this curve.

Well levels near Ferozepore A. 1·29.

H = 635·99

Time interval = 24 hours.

Z	H—Z	Log (H—Z)	log $\frac{H-Z}{H-Z_0}$	
635 37	·62	1·792		
			—·120	log H—Zo = $\bar{1}$·792
·52	·47	$\bar{1}$·672		
			—·287	
·67	·32	$\bar{1}$·505		
			—·361	
·72	·27	$\bar{1}$·431		
			—·412	
·75	·24	$\bar{1}$·380		
			—·450	$\bar{1}$·792
·77	·22	1·342		
			—·491	$\bar{1}$·230
·79	·20	$\bar{1}$·301		
			—·562	—·562
·82	·17	1·230		
			·713	
·87	·12	$\bar{1}$·079		

Mean of log $\frac{H-Z}{H-Z_0}$ = — 425 Significant

Standard deviation σ = ·166 where the interval is 24 hours.

$$\lambda = \frac{\cdot 7}{7\cdot 5 \times \cdot 43 \times 60 \times 60 \times 24} \text{ in F. C. S.}$$

$$= 0\cdot 25 \times 10^{-5} \text{ in F. G. S.}$$

$$t = t_o = \frac{1}{\lambda} \times \log \frac{H-Z_o}{H-Z}$$

$$\lambda' = \frac{1}{t-t_o} \times \log \frac{H-Z_o}{H-Z}$$

$$\lambda' = \lambda \times 0\cdot 43.$$

Ferozepore Aa_1 1·29.

H = 635 90

Time interval =24 hours.

Z	H—Z	log (H—Z)	$\log \frac{H-Z}{H-Z_0}$
635·30	·60	$\bar{1}$·778	
			—·079
·40	·50	·699	
			—·125
·55	·45	·653	
			—·301
·60	·30	·477	
			—·380
·65	·25	·398	
			—·416
·67	·23	·362	
			—·477
·70	·20	·301	
			—·602
·75	·15	·176	
			—·664
·77	·13	·114	

$$\lambda = \frac{\cdot 5}{5\cdot 6 \times 24 \times 60 \times 60 \times \cdot 43} \text{ in seconds}$$

$$= 0\cdot 25 \times 1^{-5} \text{ in F. G. S.}$$

VELLS

COMMEN

W. A L A

25

35

24

33

38

42

NEW LEAD CHANNEL

732

733

734

735

40

736

Ferozepore Bx$_1$ 1·29.

H = 636·60.

Time interval = 24 hours.

Z	H—Z	log (H—Z)	t	$(t-t_o)$	$\log \frac{H-Z}{H-Z_o}$
636·18	0·42	$\bar{1}$·623	t_1		
·28	·32	·505	1	t_1 1	—0·118
·38	·22	·342	2	t_1 2	—0·281
·40	·20	·301	3	t_1 3	—0·322
·40	·20	·301	4	t_1 4	—0·322
·43	·17	·230	5	t_1 5	—0·393
·46	·14	·141		6	—0·482
·48	·12	079		7	—0·544
·52	·08	$\bar{2}$·903		8	—0·720

$\lambda = 0·25 \times 10^{-5}$ F. G. S. units.

Ferozepore Bx_2 1·29.

H = 636·20.

Time interval=24 hours.

Z	H—Z	log (H—Z)	$\log \frac{H-Z}{H-Z_o}$	$t-t_r$
635·88	·32	1·505		
635·98	·22	$\bar{1}$·342	—0·163	1
636·03	·17	$\bar{1}$·230	—0·275	2
636·03	·17	1·230	—0·275	3
636·05	·15	$\bar{1}$·176	—0·329	4
636·08	·12	·079	—0·426	5
636·08	·12	·079	—0·426	6
636·10	·10	$\bar{1}$·000	—0·505	7
636·13	·07	$\bar{2}$·845	—0·660	8

$\lambda = 0{\cdot}25 \times 10^{-5}$ F. G. S.

DISCUSSION.

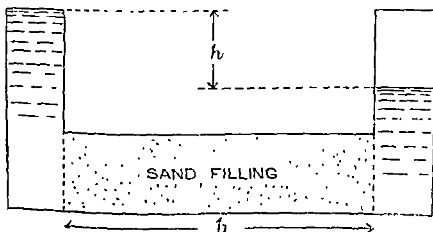
In introducing the paper to the audience Dr. Bose made the following remarks :—

In discussing the problems of subsoil hydraulics frequent references to Darcy's law have been made. Some have even expressed it as being :—

$$v = K \frac{dh}{dx}$$

For a true appreciation of this paper it was essential briefly to review Darcy's Law, with its scope and limitations.

In 1856 H. Darcy carried out a series of experiment in order to find out some empirical relation for the flow of water in a porous medium like the soil.



The above diagram illustrated the nature of his experiments. There was an arrangement for keeping the water level constant at the upstream and downstream tanks ; there was also a device for measuring the total volume of flow. So that knowing the discharge per second and the sectional area, a value for the average velocity could be calculated. Noting this for different values of head " h " Darcy found that

$$v = \frac{Q}{A} = K \frac{h}{l}$$

where v was the average velocity, Q the discharge A the cross section at area, h the loss in head and l the total length of sand.

The limitation of this Law was apparent. This relationship had been deduced only from horizontal flow ; and as such could only apply

to laminar flow in horizontal direction [illegible] flow; the other components being [illegible] law. The same relationship was dec[illegible] in the Annual Report of the United States Geological Survey by geometrical treatment of the problem of capillary flow in a porous medium. He put it in the form

$$v = 771 \frac{d^2}{K} \text{ J cms per sec.}$$

where d was the average diameter of the soil particles, j the slope $\frac{h}{l}$ and k a constant which depended on the degree of packing.

It was in order to do away with this serious limitation of Darcy's law that the tube well data were collected and analysed. Darcy's law strictly speaking was simply

$$v = K \frac{h}{l},$$

and the idea of putting this in the differential form

$$v = K \frac{dh}{dl}$$

was more a result of intuitional perception than of experimental research or mathematical analysis.

The exponential law of his paper was differential in [illegible] restricted to the horizontal nor to the free surface. Since any point had been taken in the body of the liquid for deducing this law, its application was general through out the liquid without directional or dimensional limitations.

With these remarks the Author introduced his paper.

Mr. Khosla in opening the discussion expressed the opinion that Dr. Bose's paper was a most important contribution to a knowledge of subsoil hydraulics. The general equation of flow worked out by the author at the end of his paper must be taken as a fundamental equation and not merely as a generalisation of the well known Darcy's law. Dr. Bose in his introductory remarks had already brought out the limitation of Darcy's experiments and his deductions thereform. In brief, Darcy's experiments related only to horizontal flow between parallel planes and therefore, strictly speaking his relation $v = K \frac{h}{l}$ could not be applied beyond the limits of his experiments. Darcy's pressure gradient line had

one definite slope and connoted a constant velocity and therefore a constant discharge under any one set of experiments. Its application to conditions of varying rate of change of pressure or of flow in any but the horizontal direction had no justification either in theory or from experimental data. Dr Bose's equation gave the necessary justification. It would therefore not be out of place to name this most important and fundamental equation as the "Bose Law." The application of this theory to the various engineering problems dealt with in the speaker's paper and to the fresh problems introduced in the discussions thereon by Messrs. Haigh and Montagu had been fully dealt with by the speaker in his replies to their criticism

The mathematical treatment was based on actual observations, the only substitution being his replacement, hydrodynamically of the flow of water in a porous medium by the flow of a very viscuous fluid. The deductions justified this substitutions.

Dr. Bose had dealt with the theory of subsoil flow in general and from there he had deduced the particular law of Darcy for the free surface. In this connection it might be mentioned that the filter points of the observation pipes were fixed some distance below the surface. The observations recorded the pressures at those points. During the observations those points remained unchanged so that the rise of water level in the pipes was entirely due to the period of time between the various sets of observations Thus the investigation was a true representation of the condition of flow at any point in the body mass. As such, the treatment was general and the conditions of the free surface were only a particular case

The recuperation curves of page 175 which formed the basis of Dr. Bose's [illegible]
spea [illegible]
leve [illegible]
pon[illegible]
sure [illegible]

The Author of the paper [illegible] of great importance
to the engineering profession, [illegible]
by producing a general equatic[illegible]
blems of water-logging and pumping, and to those governing the stability of structures in saturated soils. Dr. Bose's law was of world-wide importance as it was the first general mathematical deduction of this subject, and was based upon a series of reliable experimental results. While equation (*ii*) was the fundamental equation, called the exponential law of subsoil hydraulics, the equations, 23, 24 and 25 gave the general equations of subsoil velocities which were the main concern of the engineer.

PAPER No. 141.

ENERGY LOSSES OVER LONG CRESTED WEIRS.

BY MESSRS J D. H. BEDFORD & A. M R. MONTAGU.

CONTENTS.

NOTATION.

A	.. Cross sectional area of a stream.
B	.. Widths of crest.
C	.. Empiric constants.
G	.. Gauge reading (above crest level).
	.. Gravity constant.
$\tilde{H}$	.. True head acting (*i.e.*, total energy expressed in feet head of water) at downstream edge of Weir crest.
H_L	.. A loss of head between gauge site and downstream edge of crest.
K	.. A constant $\sqrt{g} \times (\frac{2}{3})^{\frac{3}{2}}$ $=3{\cdot}08880\ldots.$
M	.. Hydraulic mean depth
Q	.. Total discharge in cusecs
V	.. Velocity : V/a velocity of approach.
W. P.	.. Wetted perimeter.

ENERGY LOSSES OVER LONG CRESTED WEIRS

By Messrs. J. D. H. Bedford & A. M. R. Montagu.

The theoretical discharge over a long crested semi-modular Weir is given by the formula

$$Q = K \times B \times H^{\frac{3}{2}}$$

where Q is the discharge

K is a constant.

B is a width of the weir.

H is a head acting.

2. Some of these terms will repay a brief examination.

The theoretical value of the constant K is $\sqrt{g} \times (\frac{2}{3})^{3/2}$ and is of course a true constant in the same sense that "g" or "π" are true constants Its apprximate value is 3.08880....and in this paper K invariably represents this value.

3. The "head acting" H is the total energy expressed in "feet head of water" and is the summation of the depth, velocity, pressure energies. This "head" should be measured at the down stream edge of the weir crest where alone the minimum energy can exist.

4. [illegible]

down stream crest.

In this paper the real or "true" head acting at the down stream crest is designated by H.

5. In practice [illegible]
stream to be clear [illegible]
water surface. In [illegible]
it is the purpose of [illegible]
to exist between G and H.

6. [illegible]

The formula then becomes

$$Q = C \times K \times B \times G^{3/2}$$

This co-efficient C may vary from 0 6 to 0 9999 depending on the circumstances of each individual case.

7. The best work on the subject which is readily available to officers of the Punjab Irrigation is that of Mr. Fane in his paper No. 110 read before this Congress in 1927 and that of Mr. Inglis of the Bombay Irrigation Research Circle. In both cases, a series of curves have been drawn giving the value of (C × K) plotted for various "drowning ratios" and widths of weir.

NOTATION.

A	..	Cross sectional area of a stream.
B	..	Widths of crest.
C	..	Empiric constants.
G	..	Gauge reading (above crest level).
	..	Gravity constant.
H	..	True head acting (i.e., total energy expressed in feet head of water) at downstream edge of Weir crest.
H_L	..	A loss of head between gauge site and downstream edge of crest.
K	..	A constant $\sqrt{g} \times (\frac{2}{3})^{\frac{3}{2}}$ $= 3{\cdot}08880\ldots.$
M	..	Hydraulic mean depth
Q	..	Total discharge in cusecs
V	..	Velocity : V/a velocity of approach.
W. P.	..	Wetted perimeter.

13. Most of the hydraulic flow formulæ are related to the hydraulic mean depth M, and the enquiries of the Authors lead to a belief that the phenomena under investigation were similarly related.

M, hydraulic mean depth

$$= \frac{\text{A (Cross sectional area)}}{\text{W. P. (wetted perimeter)}}$$

But how to obtain the average of these quantities between the gauge site and the downstream crest of the weir?

14. In what follows, the Authors freely admit the consequences of approximation, based on the theoretical assumption, the results of which now to be discussed, are themselves the justification of the method adopted.

It is known tha ... ould be $\frac{2}{3}$ of the true head. ... 126 of 1929) clearly indicat ... nearly accurate to assume that the average depth over the weir crest is $\frac{2}{3}$ the true head, and to continue the calculations on this basis

15. From the true head H, derived as per para. 12 the depth, area, wetted perimeter and M were all calculated simply enough on this assumption.

Various quantities were plotted one against another, some of which revealed experimental errors which had to be corrected subsequently.

At last the following curve was traced :—

Vertically the hydraulic mean depth.

Horizontally the percentage loss of head, *viz* :—

$$\frac{G - H}{H} \times 100$$

This curve is now presented.

It will not be denied that the points plotted hereon indicate some relation———a relation which is the more remarkable in view of the admitted approximation regarding calculation of M (**vide** para. 14).

From this curve the authors submit the following deductions :—

(*i*) All the observations lie very approximately on one curve which is independent of discharge, or of the ratio of H (or G) to B of the weir.

In this respect, alone, the curve indicates a great advance over all other experiments of this nature.

(*ii*) The discharge, through the hydraulic mean depth, selects the region of the curve and automatically takes care of the ratio of H (or G) to B of the weir. This is also an advance.

(*iii*) It cannot be said to what extent the material of the weir will affect the results. This is matter for further experiment.

(*iv*) As M falls, the % loss increases; when M is small, the % loss increases rapidly.

This indicates that for small discharges smoothness of weir and material is of first importance and that a portion of the losses is of the nature of a constant, possibly dependent on the distance of the gauge site above the weir.

(*v*) As M increases the % loss falls. When M is big, the % loss decreases very slowly indeed.

This indicates that for large discharges friction is of less importance than curvature. At the worst, the "Curvature" can only be the worst possible, and the loss in that case a maximum. For large discharges this [illegible] t.

[illegible] experiments on a large scale are clearly desirable

16. The experiments [illegible]

[illegible]

mental channel at the head. The maximum depth of water on crest was taken to be 4·75 feet and the length of crest built. 4·75 × 3 feet = 14·25 feet. Actually the greatest depth obtained on the crest did not exceed 4·0 approximately.

17. Th[illegible] xperiments were made was 6·25 [illegible] walls were dismantled and rebuil[illegible] e walls being the same for all experiments. The floor was made truly horizontal with cement plaster and the width between side walls were made accurate in all cases with cement plaster; the largest variation in width on the whole length of side walls did not exceed ·008 feet.

18. All gauge readings were done by means of telescopes The water passing over the flume was accurately measured in a pacca tank that had previously been calibrated. A two way water switch existed downstream of the weir so that water could be switched into or out of the masonry tank. Six sets of experiments were carried out for width of flume as follows:—

6·25′, 3·5′, 2·2′, 1·5′, 1·1′, ·5′.

19. The results of the experiments are given in tabular form in the statements attached.

Signed for Messrs. J. D. H. Bedford and A. M. R. Montagu.

A. M. R. MONTAGU,

29th November 1929.

B=6.25′

$$H^{3/2} = \frac{Q}{6.25 \times 3.089} = \frac{Q}{19.3}$$

G	Q	$H^{3/2}$	H	$H_L = G - H$	$\frac{H_L}{H} \times 100$	$\frac{2}{3}H$	WP= $B + \frac{4}{3}H$	A= $B \times \frac{2}{3}H$	M= $\frac{A}{WP}$
1.813	44.912	2.327	1.756	0.057	3.245	1.17	8.59	7.312	0.85
1.536	34.964	1.812	1.485	0.051	3.434	0.990	8.23	6.187	0.752
1.332	28.169	1.46	1.286	0.046	3.58	0.857	7.964	5.356	0.672
1.0584	19.922	1.032	1.021	0.0374	3.664	0.681	7.612	4.256	0.559
0.778	12.414	0.643	0.746	0.032	4.285	0.497	7.244	3.106	0.429
0.527	6.775	0.351	0.4975	0.0295	5.93	0.332	6.914	2.075	0.301
0.299	2.784	0.1443	0.275	0.024	8.73	0.183	6.616	1.144	0.173

B=3.5′

$$H^{3/2} = \frac{Q}{3.5 \times 3.089} = \frac{Q}{10.811}$$

G	Q	$H^{3/2}$	H	$H_L = G - H$	$\frac{H_L}{H} \times 100$	$\frac{2}{3}H$	WP= $B + \frac{4}{3}H$	A= $B \times \frac{2}{3}H$	M= $\frac{A}{WP}$
2.407	38.184	3.53	2.32	0.087	3.75	1.547	6.594	4.425	0.671
2.133	31.745	2.936	2.05	0.083	4.05	1.367	6.234	3.905	0.625
1.868	25.898	2.396	1.79	0.078	4.36	1.193	5.886	3.409	0.593
1.6435	21.359	1.976	1.574	0.069	4.38	1.049	5.598	2.999	0.536
1.342	15.763	1.458	1.285	0.057	4.43	0.857	5.214	2.449	0.471
1.187	13.107	1.213	1.137	0.050	4.48	0.758	5.016	2.166	0.432
0.909	8.686	0.804	0.865	0.044	5.08	0.577	4.654	1.649	0.354
0.621	4.825	0.447	0.584	0.037	6.33	0.389	4.278	1.111	[illegible]
0.348	1.913	0.177	0.315	0.033	10.48	0.210	3.920	0.60	[illegible]

B = 2·2′

G	Q	$H^{3/2}$	H	$H_L = G - H$	$\frac{H_L}{H} \times 100$	$D = \frac{2}{3}H$	$WP = B + \frac{4}{3}H$	$A = B \times \frac{2}{3}H$	$M = \frac{A}{WP}$
2·980	32·59	4·790	2·840	0·140	4·93	1·894	5·99	4·17	0·696
2·572	26·34	3·875	2·470	0·102	4·13	1·646	5·49	3·62	0·659
2·345	22·92	3·370	2·240	0·105	4·69	1·490	5·18	3·28	0·633
2·133	19·75	2·905	2·040	0·093	4·56	1·360	4·92	2·99	0·609
1·850	15·99	2·350	1·765	0·085	4·82	1·176	4·55	2·59	0·569
1·533	12·05	1·722	1·465	0·068	4·64	0·976	4·15	2·15	0·518
1·166	7·96	1·170	1·110	0·056	5·04	0·739	3·68	1·625	0·441
0·518	2·25	0·331	0·479	0·039	8·14	0·319	2·84	0·703	0·248
3·478	41·07	6·140	3·350	0·128	3·82	2·230	6·66	4·91	0·740
2·986	32·78	4·820	2·850	0·136	4·78	1·900	6·00	4·18	0·697
3·214	36·46	5·360	3·060	0·154	5·03	2·040	6·28	4·49	0·715
2·560	26·06	3·830	2·450	0·110	4·49	1·634	5·47	3·60	0·658
0·757	4·07	0·599	0·711	0·046	6·46	0·474	3·15	1·043	0·331

B = 1·5′

G	Q	$H^{3/2}$	H	$H_L = G - H$	$\frac{H_L}{H} \times 100$	$D = \frac{2}{3}H$	$WP = B + \frac{4}{3}H$	$A = B \times \frac{2}{3}H$	$M = \frac{A}{WP}$
3·607	29·690	6·400	3·445	0·162	4·71	2·296	6·09	3·440	0·564
3·106	23·720	5·110	2·965	0·141	4·76	1·976	5·45	2·960	0·543
2·548	17·670	3·810	2·440	0·108	4·43	1·626	4·75	2·440	0·514
2·304	15·060	3·245	2·190	0·114	5·120	1·460	4·42	2·190	0·496
1·941	11·700	2·520	1·845	0·096	5·20	1·230	3·96	1·845	0·466
1·573	8·490	1·839	1·498	0·075	5·01	0·999	3·50	1·500	0·428
1·150	5·330	1·149	1·095	0·055	5·02	0·730	2·96	1·095	0·370
0·773	2·900	0·625	0·730	0·043	5·89	0·487	2·47	0·730	0·295

B=1.1′

G	Q	$H^{3/2}$	H	H_L =G−H	$\frac{H_L}{H}$ ×100	D=⅔H	WP= B+4/3H	A= B×⅔H	M= $\frac{A}{WP}$
3.733	22.70	6.680	3.550	0.183	5.15	2.36	5.82	2.60	4.47
3.450	20.14	5.930	3.280	0.170	5.19	2.19	5.48	2.41	4.40
3.146	17.48	5.150	2.980	0.166	5.57	1.99	5.08	2.19	4.32
2.726	14.03	4.130	2.570	0.156	6.08	1.71	4.52	1.88	0.416
2.748	14.20	4.180	2.590	0.158	6.11	1.73	4.56	1.90	0.416
2.289	10.82	3.185	2.160	0.129	5.97	1.44	3.98	1.58	0.397
1.924	8.32	2.445	1.820	0.104	5.71	1.21	3.52	1.33	0.378
1.463	5.48	1.610	1.370	0.093	6.79	0.91	2.92	1.00	0.343
1.016	3.15	0.927	0.952	0.064	6.73	0.63	2.36	0.69	0.292
0.675	1.69	0.497	0.627	0.048	7.65	0.42	1.94	0.46	0.237

B=0.5′

G	Q	$H^{3/2}$	H	H_L =G−H	$\frac{H_L}{H}$ ×100	D=⅔H	WP= B+4/3H	A= B×⅔H	M= $\frac{A}{WP}$
3.576	9.046	5.480	3.250	0.326	10.0	2.166	4.83	1.08	0.224
3.214	7.700	4.970	2.920	0.294	10.0	1.946	4.39	0.97	0.221
2.773	6.152	3.970	2.500	0.273	10.9	1.666	3.83	0.83	0.217
2.232	4.431	2.860	2.020	0.212	10.5	1.346	3.19	0.67	0.210
1.817	3.268	2.108	1.640	0.177	10.8	1.093	2.69	0.55	0.205
1.079	1.473	0.952	0.966	0.113	11.7	0.644	1.79	0.32	0.179
1.530	2.513	1.620	1.380	0.150	10.9	0.920	2.34	0	
3.723	9.621	6.210	3.380	0.343	10.1	2.254	5.01		

PROPOSED

ENING 3½" WIDE

LENGTH OF WEIR 6.25

CHANGED AFTER EX EXPT SEE NOTE BELOW

WIDTH

CURVED SLOPE
RADIUS 14 25
= 3H

PL

5

5 BRICK W

TOP OF SIDE WA

SECTIONAL
AT CEN

R = 14·25

R.L. 10·0C

WER POSITION = 9·260 R L HENCE SUBTRAC

PER POSITION = 12 046 R.L. HENCE ADD 2

= 9 276 R L HENCE SUBTRA

RIMENTED UPON WERE 6 25', 3 5', 1·5' O

THE RADII OF THE END A

R. MONTAGU
ENGINEER

ON L.B.DRAY

DISCUSSION.

Mr. Bedford, in introducing the paper, said that it might be as well to explain in a few words the reasons that led to the experiments and the little paper He said that before he took over the Upper Bari Doab Circle there was a scheme for measuring the absorption losses in the Main Canal The Main Canal had several rapids which at a small expenditure of money could be converted into a long crested weir.

It, however, seemed to him to be essential to know with accuracy the co-efficient that could be applied to the formula $D=CLH^{3/2}$ before they could hope to obtain any results from the bigger problem of absorption losses in the Main Line.

It was then with this object that the experiments placed before the Congress were carried out. The results, however, immediately showed that it was not possible to apply any co-efficients obtained from the experiments directly to the formulae for weirs in the Main Canal with a maximum discharge of 6,750 cusecs He said that while he was studying the experiments in Dalhousie Mr. Montagu happened to drop in, and on his showing him the results of the experiments Mr. Montagu very kindly suggested the line of attack, and they spent the next few days in producing the small paper.

Mr. Montagu as joint author of the paper first thanked Mr. Bedford for so kindly allowing him to associate himself with the paper. It was an extremely small paper. He deduced no law, but merely endeavoured to show from the data supplied by Mr. Bedford that it was possible to produce one curve for all the varying co-efficients for varying bedwidths and depths of crest. Hitherto it had been customary to vary the co-efficient itself; he had given his reasons for not following this process. He pointed out that the curve did not apply to all weirs but merely indicated a line of attack. If other things could be deduced from the method of treatment, so much the better, but he had not attempted to do so.

Mr. Inglis remarked that there was very much in the paper with which he was in entire agreement. He agreed that if the velocity is assumed to be [illegible] at all points in the section then the minimum energy must be [illegible] downstream end of the crest, which in that case is the control [illegible] in the sense that any modification of this section would have [illegible] If, however, the velocity is taken to vary from [illegible] to curvature caused by friction and [illegible] y the case—then there is an enforced [illegible] the throat.

Figure 1 shows an exaggerated plan showing the effective throat width B, which in practice is the control section; the portion below B acting merely as an expansion

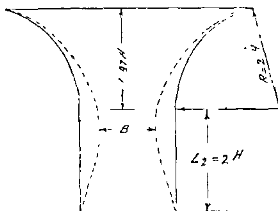


FIG 1

This is the reason why in practice it is the co-efficient that varies while the exponent remains constant within the working range. It also explains why the range of modularity increases as the width decreases for any particular depth of water—as clearly shown in these experiments when they are plotted on log paper. There was, he thought, no question that if we had two flumes which were dynamically similar, the loss would be a function of the hydraulic mean depth, and would bear an inverse ratio of the $^3/_2$ power of their hydraulic mean depths. It was unreasonable to suppose, however, that a small flume flowing at full supply

(with R

design

The d

of the flume was a constant and that this length was very great relative to the depth of water. His opinion was that the *full supply coefficient* could best be worked out on the basis of hydraulic mean depth, but that as we could not vary curvatures with depths, the effect of variations in friction, shock and eddies could not be eliminated—in other words working entirely on Hydraulic Mean Depth would lead to error. On the other hand flumes could be designed in which the discharge varied as $H^{3/2}$ within the working range with a negligible error, and he thought that such a flume was what we required in practice. In this connection his experience was that Mr. Crump's flumes fulfilled all the conditions desired *provided the width relative to the depth was not too great.* In Technical Paper No 15 of the Bombay Public

Works Department it was suggested that $B=D^{1\cdot5}$ was about the correct ratio

Further experiments with flumes of varying lengths and radii were now required to clear up the question

Mr. Inglis considered that the Paper had not merely led to the theoretical side of the question being cleared up but had also shown that there was a modular range depending on the bed width-depth ratio and that with some further experiments, preferably on Mr Crump's standard design, *it would be possible to predict the co-efficient with a* high degree of accuracy

Mr. Burkitt remarked that he had worked out a few of Mr. Montagu's and Mr. Bedford's examples and had found that the loss of head could be treated simply as friction head with N= 013 in Manning's formuls.

Mr. Lacey said that the authors were to be congratulated on presenting within the limits of a very modest paper much valuable information The method of dealing with the loss of energy between the gauge site and the downstream edge of the crest was rational and ingenious. It was stated in the paper that various quantities were plotted against one another and that finally the authors hit on the plan of plotting the hydraulic mean depth against the percentage loss of head, both to a natural scale. The curve in question was printed as a plate accompanying the paper and appeared to average the points fairly successfully. Of this curve the authors remarked that the points plotted indicated an undeniable relation, and with this statement the speaker was in entire agreement. Had the authors tried a 'log' plotting, a course of action which should never be omitted, they would have obtained the following relationship which the speaker had discovered namely:—

$H_L = 03\ H/R^{2/3}$, and when the channel is of infinite breadth

$H_L = \cdot0393\ H^{1/3}$

This curve it would be found fitted the points with considerable accuracy.

Mr Lacey concluded by saying that in a case like this when an exponential curve should be sought, the use of 'log' paper was the more imperative; of course in this instance, as the authors had pointed out, the loss was composite and due to three sources; nevertheless, a log plot might show which source was predominant, and also indicate on what lines any further attempts at analysis of the data should proceed.

Mr. Ishar Das said that after reading the paper, his first thought was that the hydraulic mean depth, which for ages was not so important in determining velocities and discharges, had again come into prominence.

He said that knowing the head available we could plot M from the curve and design the dimensions of a flume accordingly. He was

of opinion that it was desirable to abandon the idea of making H a function to determine throat widths, approaches etc, for designing flumes and to launch an effort to make a flume which would give directly on a gauge the loss of head This was, however, a matter for research.

Coming to the critical side of his study of this interesting paper, he offered the following remarks :—

1. The conclusions of the authors were based on the curve they had drawn and given at the end of the paper.

2. A parabolic curve when plotted on logarithmic paper gave a straight line the equation of this being in the form

$$y = mX^{n}.$$

the tangent of the slope of the line was equal to the exponent n and the intercept on the y axis was equal to m

3. He presented a plotting on logarithmic paper of the data of the authors' curve Three lines have been drawn, one corresponding to flume widths of 6·25, the second to widths of 3·5 and the third to the remaining four widths ranging from 2·2 to 0·5.

4. All these lines were parallel indicating that the curves represented by the straight lines were of the same family.

5. In each of the lines there was a kink between values of M of ·4 and ·5.

6. The upper part of the lines if produced would meet the y ordinate at n= 13, showing that at that value of m the loss of head was nil and that still further up there would be a gain [illegible] Probably if there were [illegible] would be more kinks [illegible] (i.e., for widths of 0·5) [illegible]

7. Generally in our designs values of M ranged from about 1 to 4, therefore more experiments were needed to cover this range and establish a law.

8 The influence of silt on the flow had also to be considered. He firmly believed that silt accelerated the flow up to a certain limit By this he meant that the same gauge would give different discharges for clear and silted water. Accepting this, the loss of head in the same would be different for water of different silt charge

9. He thought it possible that the kinks might be due to faulty design He was hopeful that a design might be evolved which would eliminate these kinks and thus establish a straightforward law.

10. He wished to thank the authors for presenting this interesting and suggestive paper which opened up a fresh line of research.

Mr. Mithal presented a graph [illegible] decreased The authors should therefore have not drawn a mean curve, applicable to all values of B, under such circumstances.

He also criticised the values of B=2·2, which he considered to be erroneous He instanced the two values:—

$$M = \cdot 715, \ \% \ L = 5.03$$

$$M = \cdot 442, \ \% \ L = 5.04$$

and enquired whether it meant that the loss between these two values of M was to be taken as 5 % only

He enquired if account was taken of the head loss in the channel between the gauging section and the flume

Mr. K R Sharma said that the correct formula of discharge for a rectangular notch was

$$Q = \sqrt{3c}\sqrt{2g}\, B H^{3/2}$$

where C is a constant which takes care of the practical errors in the formula.

The theoretical value of the constant in the above formula neglects friction and assumes a depth of $\frac{2}{3}$ H on the crest.

He objected to the assumption that the average depth on the crest is 2/3rd H. He instanced the meter flume at R. D. 10,000 Northern Branch, Lower
out to 3·05.
to the beginnir
found to be (

He quoted other cases wherein the co-efficient of discharge was found to increase with the rise in gauge owing to reduction of afflux. He concluded that the hole in the experimental flume was very near to the contraction.

The meter flume at R. D. 10,000 of Northern Branch Lower Jhelum Canal was calibrated in the month of January 1929 when canal water was clear. It had been found that when muddy water comes there was excess in the canal with the same meter gauge. The gauges downstream

this point if it was observed by them.

There were three points which were not clear to him in the working of this meter and he requested the authors of the paper to throw light on them.

(1) Loss of head in afflux upstream and entry was a loss in the structure of the flume. Should the gauge measure the loss of head in afflux on entry? How could it be allowed for in the co-efficient of discharge?

(2) Would it not be possible to do away with the unnecessary loss of head in approach to the crest

(3) Although the ideal conditions of flow were not available at the crest and the depths at the end of the crest were considerably less than 2/3rd but still the meter was working with a good co-efficient as much as 3·05

Mr. Colyer briefly reviewed the growth of the free fall formula and stated that the control section was assumed to be at the point of contraflexure of the water surface, *i.e.*, at the point where parallel flow occurred.

The depth at this point was 2/3 H. He failed to follow the authors in working back from the discharge to obtain H the depth over the crest, and disputed that the head acting should be measured at the downstream crest of the weir.

Certain other questions arose in his mind on reading the paper. For instance in paragraph 15 (*i*) he failed to see why the co-efficient was independent of the discharge which of itself was a function of M the hydraulic mean depth

Mr Colyer then quoted a number of observations of his own, used to obtain the co-efficient for various weirs, which he found, were in close agreement with the percentage losses indicated by the author's curves

Mr Khosla remarked that Messrs Bedford and Montagu had made an important contribution in introducing hydraulic mean radius (M) in the discharge calculations over long crested weirs.

He said that he had drawn attention in 1929 in connection with Mr. Montagu's paper to the effect of bed-width depth ratio on the co-efficient of discharge That effect was fully covered by the H. M. R. (M) now introduced by Mr Montagu.

He said that the data supplied by Messrs. Bedford and Montagu did not however cover a sufficiently wide range The H. M R. of the experiments did not go beyond 0·9

In regard to the curve of percentage loss of head, he remarked that there seemed to be an indication that the results for the various widths formed separate curves by themselves. Thus, for instance, all points for 6 25 were to the extreme left of the mean curve, and all points for 0·5 width were to the extreme right. For intermediate widths the points lay between the two extremes and generally followed the order of flume widths. Taking a concrete case:

For B = 6·25 m = 0·173 loss % = 8 73

For B = 0·5 m = 0·179 loss % = 11 7

or the percentage loss for the same value of m was less for a wider flume than for a narrower flume Mr. Montagu's deduction No. (*i*) was therefore open to question. His deduction No (*ii*) was not quite clear to him He requested Mr. Montagu to please explain further.

Mr. Khosla said that Mr. Montagu's investigation was an advance in the right direction, and perhaps Mr. Montagu would pursue it further

[illegible] the effect of B really persist- [illegible] find out a simple formula for [illegible]

Mr. Musto said that he thoroughly agreed with the authors' conclusions as given in paragraph 8 of their paper. From this arose the difficulty of selecting co-efficients when designing new works Referring to paragraph 15 (*iv*) he suggested that this increase of percentage loss as M falls might rather indicate the great effect of side friction. He [illegible] feet deep having bed widths of [illegible] e values of M for these would be [illegible]

Either there was something wrong with the formula for M and too much weight was given to the depth (side slopes) in the denominator, or it was evident that side friction or restriction played a far greater part than bed friction, on all problems of flow He suggested that this should be verified by experiment ; for example, on test channels of equal depth, one having 10 times the width of the other to ascertain whether the discharges of each varied directly with their H. M. D.

He further suggested testing the effect of sloping the sides of the chan[illegible] re much great [illegible] surface and [illegible] streams, and to spiral action in the bottom angles It would be an easy matter to carry out tests on two such channels having practically the same value of M.

Mr. Montagu in replying to the discussion, opened with the remark that most of his critics apparently accepted the logical nature of the method of attack suggested in the paper and then proceeded to explore the implications. It was with a view to avoiding this very thing that the authors had confined themsleves to indicating the logical reasons for their method and depicting the results in the form of one simple curve

2 The Authors now felt bound to follow up the lead given by their critics, and their general reply, which followed, covered most of the points raised

If a " Long crested " weir had infinite length, no critical section would form ; in fact if the weir surface were horizontal, no flow could take place

If the weir were merely very long, the surface of the water would be nearly horizontal (actual slope being determined by friction), and the depth would, of course, be perilously near the critical depth until the downstream crest of the weir was approached

3. (Mr Montagu produced diagram III.)

As the weir became shorter in length the distance between normal flow upstream and the critical section became shorter and therefore curvature (and its effects) became more pronounced.

The curvatures of the weir approach and departure also became important, as the weir shortened. If the approaches were perfect then the length of weir crest could be reduced, theoretically to zero.

4. Referring to diagram III, the author went on to point out that over the flat weir crest the total energy line had a downward slope (due *to friction*). *Over the glacis the total energy line still had a downward* slope, but owing to the greater slope of the glacis, diverged therefrom. [illegible] therefore existed at the downstream crest. [illegible] *This point had been dealt with very* [illegible] 1929 paper.

5. It did not follow that the critical depth occurred here ; only the critical or minimum energy. As soon as curvature of the stream lines existed, *Bernouilli's theorem as ordinarily stated no longer applied* A redistribution of the energies took place and resulted in a change in the relation of velocity, pressure and potential energies, which caused a change in depth.

But it was possible, in the author's opinion, to prove mathematically that the value of the critical, *i.e.*, minimum energy remained unaltered at the original figure.

6. This brought them directly to the first point made by Mr. *Inglis. This might be restated as follows* :—

" If the curvature of the boundary was such that the water could not follow it, then the water constructed its own approach curves, and virtually a new boundary." If Mr Inglis agreed to this the author freely admitted that a " forced " control section would immediately come into existance *which probably would differ from that* postulated by the author. If such really did take place, then one of the prime conditions of the problem no longer existed, and the actual downstream crest of the weir no longer formed the control section. But this did not vitiate the *author's argument. It merely instanced a case in which circumstances* prevented the *virtual* crest being known.

7. Although Mr. Inglis' sketch is in plan only, the departure of the stream lines from the **bed** surface of the weir might be postulated also (*viz.* in section).

In their present state of knowledge of the effects of curvature, a weir so constructed was not a reliable meter, because neither H nor B could be measured or otherwise determined.

Fortunately for the author, both Mr. Inglis (Bombay) and Mr. Lacey (U. P.) had insisted upon the author sitting down and plotting the results on double logarithmic paper and had been good enough to discuss the results so obtained. Had the Author been left to himself, he had no hesitation in stating that what he would now place before them would have taken far longer to arrive at.

Here the author produced diagram IV.

8. If the percentage loss of head was plotted horizontally against the head acting on double logarithmic paper, for each of the six series of experiments a family of curves resulted, the general nature of which was depicted in the diagram. The following deductions could be drawn at once :—

(*i*) The loss effects of curvature and friction caused a "kink" in the logarithmic curves, the position, duration and slope of which varies with the value of B (width of throat).

(*ii*) Clearly, for the *length* of crest adopted, a value of B existed for which a constant per cent. deduction from the corrected gauge reading could be substituted for the constant co-efficient advocated by Mr Inglis, for all ranges of H within the working Semi-modular range.

(*iii*) Again, by selecting another value of B, the slope of the "kink" could be utilised such that the % deduction from the corrected G varied as the 2/3 power of H, in other words that the co-efficient k might be altered and would remain *constant* for the particular working semi-modular range desired Clearly it was to this particular type that Mr. Crump's dimensions approximated and which Mr Inglis had so strongly advocated.

(*iv*) Again, it was clear that the B : H ratio was of less importance than the ratio of B to length of crest and thi again brought the curvature effect into prominence.

(*v*) If the B was at least very large, the logarithmic curve tended to sraighten out, and the kink to vanish : in the limit it became a straight line whose slope obviously was ⅓.

9. This brought them to Mr. Burkitt's contribution In the [illegible] be neglect- [illegible] lanning's N [illegible] nts, such a value would give approximately the same results Now if Manning's "N" were a true co-efficient of rugosity, obviously it would hold over any "work." Mr. Burkitt had, then, indicated to the Author a method of separating out the curvature and friction losses The Author had no doubt that a direct measurement of N in similar materi l in a "normal" channel would give a value of "N" distinctly lower, in which case the balance of the losses would be due to curvature

10. Mr. Lacey's remarks were much appreciated by the Author, particularly in regard to the use of logarithmic paper, which he heartily endorsed.

11. Most of Mr. Lacey's contribution had been answered n the preceding remarks. The Author's failure to produce a log plotting was due to the recognition of the composite nature of the source of loss and the desire not to obscure their primary object.

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12. The formula quoted by Mr. Lacey, *viz.*, $H_l = 0·03\ H\ M^{2/3}$
al officers engaged
lesign of which the
cent.—an advance

13. In reply to Mr. Ishar Das Mr. Montagu pointed out that as a result of the double log plot exhibited, a weir could now be designed, the % H_l of which would be constant within the limits of the working range. The explanation of the "kinks" observed by Mr. Ishar Das had been given already.

14. Mr Montagu took leave to point out that on a double log plot, the straight lines would never cut the Y axis at zero value unless produced to infinity.

15. In regard to silt and its effects on flowing water the Author referred Mr. Ishar Das to Mr Buckly's (Jnr.) Paper No. 4425 at the Inst. Civil Engineers, London, in 1923. The only effect that would be experienced over a weir would be due to a change in co-efficient of rugosity and would be extremely small.

16 Mr. Mithal clearly had failed to grasp the essential factor in the paper, as also had Mr. Sharma. No parallelism of stream lines was postulated in any part of the paper. In fact, the change of losses due to friction being in the opposite sense to the change of losses due to curvature had been the key-note of the discussion. The original discharge formula $Q = K\ B\ H^{3/2}$ had been derived from a simplification of Bernouilli's original law and it was the errors arising out of this simplification which were, by implication, dealt with in the paper. The reason for assuming the wetted perimeter to vary with 2/3 H were given The approximation was justified by the results.

17. Mr. Sharma's interesting remarks on the individual weirs on the Upper Jhelum Canal merely confirmed the Author's case that the accepted co-efficients were wrong.

18. The objections to crests at bed level were numerous. Hydraulically, they postulated high velocities, high losses and at present, bad curvatures.

19. The above hal
also shewed that the law
sults agreed in practice
ratios of head, bed widt
out to Mr. Colyer that the point of contra-flexure of the water surface did not indicate parallelism of flow, neither did it occur at the controlling section.

20. The word "independant" in para. 15 (*i*) was used in the sense of "not explicit."

Mr. Khosla very properly referred to his remarks on the speaker's paper No. 126 of 1929. The present paper was decidedly a continuation of that paper. The subject was without end But the Author deprecated any attempt on Mr. Khosla's part to draw separate curves for separate cases. It was to get away from this that the joint Authors presented their contribution. The resulting discussion had cleared up Mr. Khosla's other enquiries.

21. Mr. Musto has carried the discussion on one point even further. The Authors expressly declined to differentiate the effects of the various sources of loss of energy. The discussion has compelled the speaker to shew how curvature and friction losses are essentially separate, but Mr. Musto wants to determine the relative effect of side and bed [illegible]

22. If what Mr. Lacey has termed the "isotacs" in a section of a stream are distorted, the frictional effect is more pronounced. It follows that a vertical sided channel is likely to require a slightly steeper slope than a channel whose sides are "natural" for the same discharge

But all the flumes tested by the Authors and generally used in practice, had vertical sides, in order to eliminate any such consideration.

PAPER No. 142.

STABILITY OF WEIRS AND CANAL WORKS.

AN APPLICATION OF THE NEW THEORY OF HYDRAULIC GRADIENTS

By Ajudhia Nath Khosla, B.A., I.S.E.

Introduction.

In a former paper, the laws governing the flow of water in subsoils as affecting the stability of structures, resting thereon, have been clearly brought out and discussed It has been shown how the pressure gradients under the floors of weirs, etc , differ so widely from those of Bligh, which latter, have formed, so far, the basis of our designs of such structures. It has also been shown how the shape of the pressure gradient curve determines the static uplift of floors and also forms the measure [illegible] from beneath them. The influence [illegible]

[illegible]

have been collected and scrutinised and are presented in a form readily applicable to the study in hand Among the old weirs, Narora of the Lower Ganges Canal, Rasul of the Lower Jhelum, Marala of the Upper Chenab have been discussed Regarding Khanki, a mass of data is said to be available which, if so, shall be studied and presented at the Congress. Of the new weirs, only Sulemanki has a series of pressure pipes in the weir floor and elsewhere, which have given useful information. No pressure pipes exist either at Ferozepore or at Islam; but a series of them if inserted in these two weirs should be most helpful in a study of pressure gradients under different conditions of geological formation, etc Data are being collected for the Jaba crossing of the Upper Jhelum Canal and Siswan Super-passage of the Sirhind Canal where the history of trouble and the record of pressure pipe observations extends over a series of years.

Some important features of the trouble, the repairs and of the structural details of general interest at the Dugri No I, and Jauryan syphons of the Upper Chenab Canal, have also been described

There is, perhaps, an enormous mass of useful data lying buried and lost in the oblivion of our Divisional files, and if this paper can succeed in exposing some of this to the light of the day, it shall have amply requited the labour spent on it.

In a general discussion of the stability of weirs, it is impossible to brush aside, altogether, the other factors, besides the uplift and the undermining due to pressure gradients in subsoil flow, which cause damage and destruction to the loose stone protection, the blocks and the impervious floor. But only a passing notice has been taken of these where necessary in order to keep the paper within reasonable bounds.

Cracks in Jauryan Floor.

Before proceeding with a discussion of the weirs, it is desirable to ... lled Jauryan ... settlement is

Plate I shows the location of cracks on these floors. The pressure gradients in both cases were above the critical just before the crack x or y occurred There must have been a cavity underneath as a result of slow but continuous undermining and the slab must have been suspended at odd portions of the soil which were intact. These last points ... It is noteworthy ... 1929 the pres- ... 84 respectively, ... alent to spring formation. The same thing happened with pipe No. 4 on 16th August, 1929. The water level dropped by 0 8 feet and the crack y developed.

Dates.	No. 10.	No. 11.	Canal.	Cunette	Remarks.
23-9-29 ..	786·26	783 43	92 27	81·44	Crack x developed on 25-9-29. Canal and cunette level almost steady.
25-9-29 ..	784·11	782·59	92·25	81·43	
Difference ..	2 15	0 84	0·02	0·01	

Dates.	No. 4.	Canal.	Cunette.	Remarks.
16-8-29 ..	86·66	91·72	81·6	Crack y opened on 17-8-29 Canal and cunette almost steady.
17-8-29 ..	85·86	91·90	81·6	
	0·80	0·18	0·0	

The overseer incharge noticing this sudden fall in the pressure level wired that something unusual had happened, and right enough there was a crack shortly after. In more than one instance, cracks have occurred immediately on the reduction of supply in, or complete closing off of, the canal. In high supply the upward pressure under the floor kept the floor s [illegible]
r [illegible]
c [illegible]
upwards pressure

The settlement of the inverted filters and the scour at the end of these are noteworthy. They explain exactly how floors are undermined This settlement happened both Upstream and Downstream and has been filled up, along with the scour holes at the end. Similar settlement has occurred to a smaller extent at the ends of the Dugri inverted filters. The structural details about the repairs and the remodelling of the Jauryan and the Dugri siphons are of considerable interest and are briefly dealt with later on.

The Narora Weir.

The Narora weir has been specially selected, as the theory of hydraulic gradients in relation to weir designs started from there

A description of the failure of part of this weir, the repairs and the subsequent additions of a long and impervious floor on the upstream side, ending in a line of wooden sheet piles 18 to 19′ below floor, is given in paper No. 7 of the 1913 Engineering Conference at Simla, by Mr C H. Hutton and in the Editor's notes by Mr F. W Woods on Chapter VI, pages 185 to 193, of the Design of Irrigation Works by Bligh Mention is also made of this by Mr Beresford in the proceedings of the Institution of Civil Engineers 1904, pages 76 and 77

Briefly, the failure of 30th March 1898 occurred due to:—

(i) Washing away of the Upstream 30 feet puddle apron and the 20 feet loose stone apron, exposing the crest wells 7·5′ to 9′ below bed level

(ii) Retrogressions of levels Downstream.

The failure of the upstream floor and protection increased the pressure under the floor and the retrogression of levels downstream encouraged piping through the imperfectly closed interstices between the circular wells of the downstream toe wall. In this connection reference is invited to para 1, page 149 of the paper on Hydraulic Gradients in Subsoil Flow, showing how scour holes close to the pacca work, increase the tendency to piping and hastens failure This piping through the interstices of the toe wall blew out sand from underneath the floor and cavity formed. Borings revealed cavities under the crest wall and floor extending 50′ on either side of the point of fracture. The cavity was 8′ deep where the spring burst through the lower line of wells and out into the grouted pitching. The lower part of the floor

settled and separated from the top, which was, in turn, lifted up by the increased pressure which worked its way in between the two layers of masonry. The above description, causes and conclusions are based on the accounts given by the authorities quoted above. *Attention in this connection is invited to* Damage to Bay No. 4 (downstream) of Marala Weir 1929, explained later on. (Plate IV.)

It is at this weir that Mr. Beresford ordered the first pressure observation pipes to be fixed in the year 1898 which were actually fixed on 27th March 1898. Colonel Clibborn's experiments were apparently carried out in this connection. Mr. Bligh evolved from these his theory

The Executive Engineer, Narora Division, very kindly supplied his original file of observations in September 1929, from which typical plots have been made to elucidate the discussion.

In plate II, figure 1 shows a section of the Narora weir with its pressure pipes, crest and toe walls, the original puddle floor (30' wide) upstream, the subsequent additions and the upstream end sheet piles. Explanatory notes are given on the drawing.

Figure 2 shows the observations, with the original floor and those after the additions.

The H. G. Lines, according to Bligh, have been plotted in both cases, with c=15 (H. G.=1/15) and the line of creep assumed to hug the underside of the floor, down the sheet piles or wells and up again. (vertical = twice horizontal).

The Upstream levels in both cases are almost the same (584·2 and 584·4).

Case, 1. Downstream levels 574·9 and 574·8 respectively. The effect of the extension of floor by 80 feet of the addition of the sheet piles is that in pipe No. 2 there is a drop of (579·41—578·07=) 1·34 feet and a drop in pipe 3 of (578·73—578·07=) 0·66 feet—an insignificant achievement considering the cost.

Case, 2. Downstream levels 572·9 Upstream levels as above. In this case pipe No. 3 is actually higher by about 0·3 than in the original design and pipe No. 2 is lower by 0·5 feet, showing that in the worst **case the pressures under the pacca floor are practically uneffected by the extensions.** The only useful part of the extensions is the 3 feet high biff wall downstream and the adjoining 25' × 1½' concrete slab. The rest of the additions appear to have been unnecessary, altogether.

Bligh Theory and Actuals.

The figures 4, 5, 7 give a clear conception of the Bligh H. G. line in relation to actual facts At the downstream floor, the only part of the structure subjected to upward pressures, **the Brigh Line is dangerously below the actuals.**

The question arises then, why are all these numerous structures based on the Bligh theory still standing.

A general reply is impossible but each individual design can be separately analysed. But there are two important po nts which allow a large margin of safety.

1. The full upward pressure never comes into play unless there is a cavity or spring line underneath the floor.

Water in the bound condition cannot exert full upward pressure on the entire area of the floor which is in contact partly with the soil particles and partly with water The effective area on which the full hydrostatic pressure can act, is [illegible] foundation soil. Thus the averag [illegible] be a certain percentage (perha [illegible] cated pressure. Immediately, however, a cavity forms and the underside of the floor comes in contact with an open sheet of water, the full hydrostatic head is exerted and were it not for the shear resistance of the masonry of the floor, which comes into play, some of the floors may be endangered.

2. The actual weight given in the floors is generally in excess of the requirements as given by the Bligh method **The Engineer's instinct adds where theory is wanting.**

Mr. Hutton in his paper has attempted to show that the observations are in accordance with Bligh's theory if the line of creep is modified Tested in the light of original observations, there seems to be no relation at all between the calculated and the observed.

Figures 3 to 8 show, for the three observation chains, the effect of varying the Upstream level with the Downstream kept more or less constant. The results are fully in agreement with those of the Dugri and Jauryan siphons It is therefore clear that **the apparent water surface at the downstream of a work is no indication of the true spring level there.** It is always lower and the difference between the true spring level and the apparent water surface gives the unbalanced [illegible]

[illegible] of part of the Narora weir is also apparent But a question has been asked why all our falls, etc. do not fail, if the true spring level is higher than the apparent spring level as indicated by the level of flowing water downstream, when the downstream water level falls in a closure. The following explanation is offered :—

Response of subsoil flow to application or withdrawal of outside head.

When the canal is running there is the head of that water on the floor. When the canal is closing the water level downstream also falls.

The saturation

neously so that

no disturbance

spring level in the vicinity of a canal or river to adjust itself to the rise

precipitation coincided with the early part of the ground water measurement." The velocity found was 6·4 feet a day. On July 3rd the experiment

flow. This is stated by him to be an actual case and as such is of great importance. He has not discussed the time factor. His observations are in kee

Slichter.

drawal of s

The following observations are reproduced as an illustration.—

Date.	Time.	Canal gauge.	No 8	No. 11.	Remarks.
		Jauryan Siphon U. S.			
1-6-27 ..	10 a m.	82·44	82 30	81·54	Canal opening. These pipes No. 8 and No. 11 are shown on Plate I.
	12 a m.	86·75	83·60	82 04	
	2 p m.	87·75	84·10	82 54	
	4 p m	88 90	85 00	82 74	
2-6-27 ..	10 a.m.	89 50	85·50	83 54	
	12 a m.	89 70	86·10	83·74	
	4 p m.	89 90	86·10	83 84	
3-6-27 ..	10 a m.	90 00	86 81	83 94	
	12 a m.	90 00	87·01	83 94	
	4 p.m.	90 10	87 01	84·04	
4-6-27 ..		90 40	87·11	84 14	

Dates.	Time.	Canal.	Cunette	No 1	No. 5	Remarks
			Dugri Siphon U./S.			
15-7-29	..	Closed				Canal opening. Pipes I and 5 are 35 and 85 feet respectively from water edge.
11-2-29	..	.	.	86 33	85 76	
11-2-29	. M	790 05	88 80	89 53	87·16	
	N	90 71	88 90	90 03	87 26	
	E	91 44	89 04	90 73	87·76	
12-2-29	.. M	91·74	89 82	91·03	89·06	
	N	92·14	89·98	91·33	89·36	
	E	92·34	90 05	91·63	89·66	
13-2-29	.. M	93 00	90 50	92 13	90 66	
14-2-29	.. M	93·2	.	92·53	89 86	
15-2-29	.. M	93 9		93·13	90·66	

Dates	Canal gauge	Cunette W L	No 8	No 11	No 17	No 18	Remarks
27-8-29	91 56	82,54	87 03	84 26	85 73	86 41	Jauryan siphon upstream showing effect of withdrawal of external pressure Pipes No 17 and 18 are outside the pacca floor, 120 ft away from water edge with strainers about 30 ft below floor. Canal closing
28-8-29	84 08	81 60	83 75	82 43	83 36	83 75	
29-8-29	83 50	81 71	83 20	82 67	83 14	83 33	
30-8-29	82 85	81 20	82 67	81 96	82 61	83 33	
31-8-29	82 80	81 1	82 55	81 71	82.51	82 73	
1-10-27	92 40		87 82	84 42			
4-10-27	9130		87 42	84 22		..	

Rest House Compound. The Canal dropped from 775·2 to 768·0 in 24 hours (April 10 to 11, 1928) and to 766·2 till 14th. The Spring level gradually dropped from R. L. 773·5 on the 10th to 770·0 till 18th and stayed at 769·7 till the canal started to rise again. This was 1,200 feet away. The drop in spring level, in the vicinity of the fall, must obviously have been much greater and quicker.

This property of quick response of sub-soil flow to external application or withdrawal of pressure is of great importance in a study of our waterlogging problem. It emphasizes the supreme necessity of efficient **surface drainage** and the evil consequences of ignoring this drainage. Drainage operations in the Marala Division substantiate this statement. The remarkable drying up of the large marshy areas on the Main Line Lower (Upper Chenab Canal) as the result of the lowering of the supply in the canal is a good illustration in this respect.

Deep curtain walls at upstream end.

the Narora Weir (plate III). It might be noticed that out of a total drop between Upstream and Downstream levels almost 45 % is lost up to pipe 1A. The same phenomenon is noticeable in case of pipe No. 2 before the extensions were done.

In the original design there was the 30 feet floor of stone over puddle at top R. L. 578 and a line of wells under the crest (bottom R. L. of curbs at 564 or perhaps 563·5). Thus there was a depth of 14 feet and

in the first case and to pipe (1 A) after extension, is very nearly the same.

Mr. Woods in his editorial note suggests **loss of head at entry** as a possible explanation. The velocity of entry is, however, so small that such a big loss appears unlikely. It perhaps does account for a small part and experimental work is needed to determine this extent.

Loss of Head Curve for downward vertical flow.

In connection with plate VII of the Paper on Hydraulic Gradients etc., the nature of flow as a result of withdrawal of head of 3 8 feet from the normal gradient line has been discussed If instead, a 3 8 feet head is superimposed on the N. G line, similar flow should naturally occur in the reverse direction, the velocities decreasing from top down and so also the pressures but following a curve of the same family as the loss of head curve of plate VII.

A curve has been derived from the observations at chain 32. (Pl III). The fall between upstream and downstream levels has been plotted on the left hand horizontally as A B and the loss of head up to pressure pipe, IA, has been plotted [illegible]
effective head at that point [illegible]
is exactly equal to D E. [illegible]
or D. This gives three [illegible]
approximate curve was run through these and other points were tested on this curve. With small trial and error the final curve of plate III was worked out It will be seen that points D, D_2 D_3 D_4 and D_5 lie on the curve as close as can be expected The equation of this curve is $y+64{\cdot}5 \log h = 64{\cdot}0$. The constants in this equation depend on the point where observations start (H = 9·8 being the starting point here).

[illegible]

superimposed head, the rate of loss of head and the velocity, both, decrease as the depth increases. In the example under consideration for a 9 8 feet head, an 18 feet deep sheet pile is responsible for a loss of 4 65′ and is therefore equivalent to a horizontal length of 15×4·6=69 75 feet with Bligh's c=15 A deep curtain wall at the upstream end is also useful in preventing sloughing of foundation sand in the event of a scour hole forming close to the pacca work as happened at the Narora Weir.

The Rasul Weir.

On page 197 of Bligh's book a set of observations is given regarding the Rasul Weir. Unfortunately no other observations could be got out of the Rasul Division and criticism on an isolated case cannot lead to much. The shape of the Hydraulic Gradient line is much the same as in the Narora Weir and exhibits the same general features This figure is reproduced here for the information of the reader as plate IV

The damage to Rasul weir during the record flood of August 1929 *is of considerable professional interest and has a definite bearing on this* paper. In certain bays the damage is on the upstream of the crest, in others it is downstream and in bay No. 4 the upstream floor, the crest and the downstream floor are all gone.

Apparently the oblique and cross flow during the flood damaged the *upstream and downstream loose protection by swirls, surging and* scour, causing deep holes close to the shallow curtain walls at the upstream and downstream ends of the weir floor. This resulted in sloughing of the sand foundations at the upstream end and piping at the downstream end. The middle portion of the weir was possibly damaged by the standing wave. At one place in bay No. 5 the top "Kharanja" has lifted up by 2½ feet above the flat masonry, the shape of the "blister" being much the same as at Marala described later on. The further details of this damage with causes that led to it, will, perhaps, be described by one of the local officers at the Congress.

Standing wave below weir.

Plate VII shows a ty [illegible]
1st September 1928 at [illegible]
Kharanja at the trough. [illegible]
the trough but a height of nine feet has been observed during the flood of 28th August 1929. The observed profiles will be exhibited at the Congress. The upward pressure at each part of the "blister" or lifted floor is shown at right angle to this floor and it will be seen that the [illegible]

masonry or concrete can be properly keyed to each other, no damage will occur provided the overall thickness of masonry is strong enough for the maximum upward pressure at the trough. But directly the standing wave travels down due to retrogression of downstream bed, etc., and forms at the block or stone protection, a double action sets in. The back pressure of the standing wave tends to lift up blocks and stone. At the same time this pressure has a tendency to get relieved through the interstices between the blocks or stone This second case exactly corresponds to the conditions of Plate VII of the paper on pressure gradients, etc. Piping starts with vigour from underneath the blocks or stone and finally extends to the foundation soil beneath the pacca floor causing failure.

[illegible]

tude of loose protection.

The Marala Weir.

Some pressure pipes were inserted in the downstream floor of this weir in 1926-27, and it is hoped, more will be put in this year at suitable points. The results of these when available will be of interest.

In the record flood of 1st September, 1928, in Bay No. 4, as also in some others, the top 'Kharanja' of the downstream glacis Lifted up, the layer of stone masonry underneath remaining intact. This lift up [illegible] ch was about 8 [illegible] under the top [illegible]

which happened very nearly at the trough, where the difference in pressure was maximum. The up-lift is shown in Photograph No 1 and Plate VII.

In the second record flood of 28th August 1929, a similar uplift occurred at and above the B line of wells accompanied by a slight settlement of the masonry floor underneath The well line B also appears to have settled in part of the damaged reach This is clear from the fact that there is a hollow underneath the concrete blocks laid diagonally and true, in 1928-29 to replace the Kharanja layer that had lifted. They are still at the true designed level so that the hollow underneath can only mean settlement of the wells and the flat masonry below the Kharanja (See Plate V).

The damage apparently started with the loose stone protection getting washed down with the immense volume of water or sucked out by swirl action due to oblique flow and then carried away, very likely the latter is what happened With this stone gone, the concrete blocks followed leaving the face of the well line C more or less exposed resulting [illegible]

level of wells of 777·8.

[illegible]

masonry and stone having been carried away by the volume of the flood.

Here it may be mentioned that undermining can occur even if the stone apron is in tact provided that the block protection adjoining the [illegible]

spaces between them were filled up [illegible]
usually carried away with the curre[illegible]
stone under the blocks and finally [illegible]
undermining of the blocks started both due to suction caused by surface [illegible]

[illegible]

against this class of damage occurring every year, the new blocks were poured in between side walls of Kattals (spawls) which by their projections into the blocks on either side prevented dislocation but permitted settlement. The spawls thus wedged in, did not move out and away with the current. Repairs done in this way have proved satisfactory. By some strange process water will move wide blocks (as much as 12 feet wide block of masonry 1½ to 2 feet thick, has been seen bodily moved at Marala). *The only way to secure them effectively, without impairing the pervious and flexible nature of protection, is to stand them on end or to interlock or wedge them as explained above.* This also points to the necessity of filling up spawls in the spaces between blocks where such have been removed. This part of the repairs is as important as the replacing of or repairs to the missing or damaged blocks.

The Khanki Weir.

A large mass of pressure pipe observations is said to be available regarding the Khanki weir. If so, it will be collected, scrutinised and presented at the Congress.

The Sulemanki Weir.

Out of the Sutlej Valley Weirs, this is the only one which has pressure pipes in the weir floor and elsewhere. Unfortunately a large number of the pressure pipes are blocked since June 1926 but a sufficient number of pipes are still in working order and the representative observations have been plotted on Plate VI.

[illegible]

downstream levels. Compare curves 1 and 2 of fig. 1 and 1 and 2 of fig. 3. In other words there is greater flow through or underneath the sheet piles in higher heads.

(ii) Most of the head is lost at the sheet piles and even under the worst conditions the pressure gradient at the downstream floor remain flat and safe.

(iii) The pressure pipe levels under the downstream floor are governed by the downstream water levels and very little by the upstream water levels.

The selection of site for this Weir has been very happy and the bedding of sheet piles in the 10 feet thick clay layer, very sound and fortunate. This clay layer underlies the weir floor and extends both upstream and downstream. How far? It is yet to find The flow that occurs can be either through the sheet pile interlocks, or through the clay or through the sand underneath this clay. Whatever way it may be, it is clear that the sheet piles bedded as they are in clay are very effective, and as far as the present study indicates, this weir is safe against piping due to subsoil pressure gradient, inspite of the shallow downstream end toe wall, if the clay remain intact. The dislocation of blocks due to standing wave or other reasons may, however, cause trouble and it might be advisable to consider putting in a line of sheet piles at the end of block protection

The retrogression of bed levels at this weir requires separate consideration but the proposed line of sheet piles will help.

Jaba Level Crossing Upper Jhelum Canal.

This will be an interesting study as there has been trouble, repairs, extensions and a series of pressure pipes observations at this work As the data could not be obtained in time, their discussion will be presented at the Congress.

Structural Details of Siphon Floors.

As there are some novel features in the design of the approach and exit floors of the Dugri siphon, a brief outline of these is given here.

[illegible]

there is either no flow or flow with good velocity.

The upward pressures under the floor slab were based on actual observations of spring level These were between 5' and 6' at the [illegible]

was des[illegible] to protect It was decided to put in a reinforced [illegible]

uniform upward water pressure less the weight of the slab. These reactions and the moments were calculated by the theory of 3 moments both for 2 spans and 3 spans Thus the [illegible] double the [illegible] is either a [illegible] slabs [illegible]

slabs being tied by verticals. In the case of the Sambarial siphon, the height of the centre walls worked out to 22 feet and it was decided to take the two centre walls only 8 feet high, the balance of the load being given by earth filled up to necessary height over a reinforced concrete roof slab.

The reinforcement of the bottom slab was calculated both for uplift and for settlement due to cavitation underneath The full upward pressure of water was taken for calculations although it was realized [illegible] prevents further development which would surely occur in case of a light floor which could remain suspended under low pressures, permitting direct passages to water between the underside of the slab and the foundation soil. The junction of the new floor with the old floor at the face of the barrels was a work of some difficulty and required careful supervision If this junction had been left faulty, blowing up would have started [illegible] has proved very successful.

Unless the slab of the cunette runs under the entire floor, as in the case where the high floor consists of sand filled, R. C. Boxes, the junction of the cunette floor slab with the side walls is very important. They must be rigidly fixed, as any break along the joint will start piping under great pressure and endanger the structure by undermining. This is how failure occurred after the repairs of 1923-25 at the Dugri No 1. (Photo 2).

Another important point was the securing of sheet piles at the end to the floor as a leak between the top of the piles and the bottom of the slab would have been dangerous. This was achieved by passing [illegible] a toe wall to give a good bedding to the top of the sheet piles.

At the end of the pacca floor an inverted filter has been given con- [illegible] ballast [illegible] thickest [illegible] been [illegible] They have pushed the springs and sand blowing at a safer distance from the structures. In the immediate neighbourhood of the pacca floor they let

clear water out and not the sand, **thus relieving pressure without permitting piping.** The thickness, grading and width of these filters is an important matter for further study for different soils and different heads. This width is recommended as 1½ to two times the critical depth and the thickness about one-third of the head In weirs these dimensions will be governed by other factors besides and it is not proposed to discuss these here.

Cement grouting under pressure.

A point of great importance was the repairs to cracks in the barrels and the filling up of cavities underneath This was done by cement grouting under pressure and has been very successful In some of the cavities as much as 30 bags of cement were consumed

In the floor or in the barrels, at the site of cracks, or wherever hollows were suspected under the floor, holes were drilled and 1¼" diameter G. I. pipes were inserted about 6" to 9" inside and 6" sticking out with a screw thread at the outer end. These were made tight against the structure by a mixture of Soda and cement mortar which has the property of setting instantaneously To the end of these pipes was screwed a 1¼" flexible armoured hose which led to the grouting machine. This machine is double acting. Two tanks of about 25 c ft capacity are employed, one containing the cement grout with or without a mixture of sand, and the other clear water.

The suction hose of the grouting machine is inserted in the water tank first and is worked to clean the delivery pipe It is then inserted in the [illegible]

[illegible]

not fill up and th amount of cement that goes in, is in some case very surprising. It may be mentioned that a relief pipe is always fixed in conjunction with the grouting pipe so that while the cement grout lodges in the cavity, the water which is already there can be forced out An exit for the water, air and cement froth is necessary to give place to the grout under pressure, otherwise, the cement surrounds and imprisons them. It must be [illegible]
be cleaned [illegible]
out of the [illegible]

Cement can be saved by addition of sand in the grout, the highest workable quantity of sand being half to equal volume of cement With sand the choking of the pipe occurs freely. The best procedure is to use pure cement where the spaces have formed between masonry and masonry owing to settlement of one layer more than the other. But [illegible]

[illegible]

result that there are series of lumps of sand, cement and cement froth. The job is not very satisfactory.

In remodelling the siphon floors some of the old work had to be dismantled where grouting under pressure had been done. This exposed regular seams C G. (photo 3) filled with neat cement grout giving a most perfect joint between the two layers of masonary which had separated by unequal settlement. These seams were as much as 1 inch or more in thickness. The grouting under pressure besides filling up cavities, impregnates the foundation sands and forms a lean cement and sand mixture, which in setting becomes very much more resistant to undermining than the original sand. It fills up all masonary joints which come in its way and fills up all pores in concrete. The latter fact was noticeable when with grouting under the floor slab of the Jauryan siphon, some air bubbles started coming out at some places through the pores of the concrete slab. They continued for a while and then automatically stopped showing that the pores have been filled up under pressure. Such operations must however be carefully watched so as to prevent damage by uplift of any weak portion of the floor. In one instance the effect of grouting was noticed through a relief pipe 45 to 50′ away from the grout pipe.

Further Observations and Laboratory Research.

Before closing the paper it is desirable to indicate lines on which further observations and laboratory research may be usefully carried out. A set of pressure pipes with filter points at the bottom, should be fitted in weirs and some selected falls at selected points so that they can indicate

Loss of head

i. At entry

ii. Under the vertical drop wall of a fall or under upstream line of sheet piles or wells in a weir and also at different depths from surface down.

iii. Upstream and downstream of intermediate curtain walls both immediately under the floor and at the bottom of these walls, and at different depths from surface down on both sides.

iv. At the end curtain walls (Sufficient data in this respect are available at the siphons dealt with in the paper on Hydraulic Gradients etc.)

v. At the junctions of wing walls and floors.

Not till such information is collected in fuller detail in the field and in the laboratory, can we hope to lay down any scientifically correct theory about Hydraulic Gradients as affecting Design of Structures on Saturated Soils.

In the laboratory experiments should be carried out with models of weirs and falls with varying depths and locations of end and intermediate curtain walls and also without any wall at all. The conditions should be as near the natural as possible. Both flat and sloping downstream floors should be tried.

Pressures should be observed at different points along the vertical both for downward and upward vertical flow Flow line contours should be studied along with velocity heads at different points and at different depths. The intensity of flow between the foundation soil and the underside of a floor slab and down and up along the sides of the lines of wells or sheet piles should be carefully studied, as this flow along the line of creep is an important factor in determining the stability of a structure. Colonel Clibborns has exhibited one such observation in figure 5, plate, I, as reviewed through a glass front On page 204 of Freeman's Hydraulic Laboratory Practice the following occurs: "The tests, a continuation of those shown in figures 106 and 107 (pages 116 and 117) were conducted for the purpose of studying the phenomenon of seepage. Although the water pressures in the lower sections of a dam are greater than those in the upper sections the tests showed that the velocity of seepage water throu[illegible]

In tl[illegible]

warc[illegible]

the c[illegible] wall. The above remarks are illustrated by photographs on pages 490-494. These along with pages 423 to 425 are well worth perusal in this connection.

A prac[illegible]

of structur[illegible]

analysis on[illegible]

useful contribution and for that reason the best place for the research is the Research Laboratory at Lahore with its glass flume and other fa[illegible]

lines and lines of equal velocity potential as effected by obstructions of different [illegible]

designs

Conclusions.

For want of fuller data the conclusions are necessarily provisional unless and so far as the text of the paper has already proved.

i The accepted theory of the hydraulic gradients as applied to designs of weir floors etc as adopted by Mr Bligh and reduced to an empirical fo[illegible]

facts and car[illegible]

tions at the [illegible]

Canal and by those at the Narora weir.

ii. The structures designed on this theory stand because the instinct of the engineer put in where theory was wanting.

iii. Except in pervious weirs of the Okhla and the Sone type where pressures get released without damage all along the path of flow, it is [illegible] prevent undermining by piping due to the uns en head between the true free water surface and the apparent water surface, downstream of a weir or over a siphon floor. [illegible] one under the weir crest, are [illegible] occur due to standing wav[illegible] walls also ensure against damage due to sloughing of saturated sand in case of deep scour holes forming close to the ends of the pacca floor. The [illegible] Pressure [illegible] water [illegible] ie class [illegible] ncrete **monolithic weir** or a reinforced concrete floor of a siphon are risky as the structure being rigid, small cavities will not be discovered, the action will continue and perhaps **the first warning may be a collapse.**

iv. An inverted filter at the end of the downstream curtain wall is a great factor of safety as it permits passage fo water and prevents sand-movement in the close vicinity of the work. The importance of the proper maintenance of the upstream and downstream stone protection, inverted filters etc. of weirs (and siphon floors) are too well known to require comments. The text has shown how the piping may commence in an otherwise sound design if the bed of the channel drops, at the end of an impervious floor by local scour or retrogression. The loss of head curve drops, giving increased pressures for the same depths below the bed, thus inducing piping.

v. Structures have failed by subsidence due to undermining more than by uplift. The uplift comes in with the full upward pressure (due to subsoil pressure gradient or the back pressure of a standing wave exerted at the trough. Marala weir floor uplift in 1917-28-29 are instances of this latter) working its way in between the top and bottom layers of masonry and concrete which may have previously separated owing to settlement of the lower layer, faulty workmanship, lack of adhesion of mortar or to the upper layer expanding or contracting more than the lower owing to changing temperature conditions. The adhesion between different layers of masonry or concrete laid at different times must receive the most careful attention, as, while a thickness of floor may be adequate, if monolithic, it will become unsafe as soon as any layer separates permitting water to enter in between and to exert the full hydrostatic pressure which anything less than the full thickness of floor cannot safely stand.

vi. The correct place to put relief strainers (which must be the approved metal strainers like the Tej with slits as fine as possible and not

the old type of pipes filled with graded ballast) is the toe wall, and the correct spacing, to be effective, is determined as explained in the text They are useless in the body of the work unless placed very close all over, for their influence is local, and does not in the least effect the True Hydraulic Gradient Line.

vii. The pressure or hydraulic gradient under a floor is a straight line joining the Upstream with the downstream True water surface, as distinct from the level of the tail water, unless modified by curtain walls, the correct influence of which in regard to depth and location has yet to be studied.

viii. The true water level or the spring level at the tail of a weir or fall or on a siphon floor is higher than the visible water level and the difference from the true to the visible determines the extent of possible [illegible]

ix. *There is a critical head for each class of soil which will start* getting dislocated under heads in excess of the critical. The undermining of foundations is a slow process of degradation and not as usually understood in tube well practice, due to the fine grains of sand getting washed out of the *interstices* between the coarser grains

The critical head for the Punjab sands ranges from 6 inches to one foot, but the fact requires confirmation.

x. Interlocked steel sheet piles are more efficient in boxing foundation soils than wells unless the interspaces between the latter are satisfactorily filled down to the bottom with the aid of a water jet. The [illegible]

result in undermining.

xi. The flow through subsoil gives a very quick response to any superimposition or withdrawal of outside pressure.

xii. Scientific research in laboratory and in field is required in right earnest, to evolve the correct theory of pressure gradients in saturated soils in relation to length of floor and depth and location of curtain walls, to replace the existing faulty conception of it The results expected are of sufficient importance to justify the expenditure involved.

Acknowledgments.

The author is grateful tc [illegible] whose help, encouragement an [illegible] for the author to initiate and [illegible] three years.

Acknowledgments are due to Mr. M. D. Mithal, Sub-Divisional Officer, Headworks, who has considerably helped the author in collecting and collating data and to Mr. A. B. Malik, Temporary Engineer, who did the observation work with great care, and P. Gian Chand, Overseer, who in addition to carrying out experiments in a scientific manner put up some original suggestions at different stages of investigation. The works of Mr. Wilsdon, Dr. Bose and of other authors drawn upon have already been acknowledged in the text.

Photo No 1

Bay 4 Marala weir, after record flood of 1st September 1928 showing uplift of top Kharanja due to back pressure of standing wave about 8ft. high.

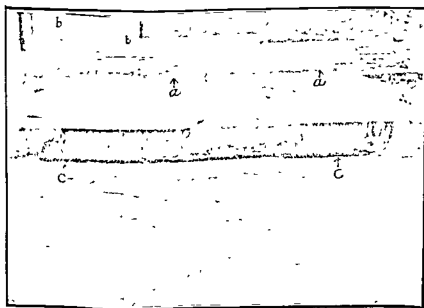


Photo No 2.

Dugri 1 Upstream floor (January 1929, before remodelling).

Showing cunette wall separate from floor CC.

Tremendous quantities of sand continued blowing through this crack close to e face of the barrels

Note also a crack between floor and wing wall aa, and crack in wing wall bb.

Conclusion.—Side walls and floors should be rigidly connected by vertical inforcement to ensure settlement of the whole mass in one.



Photo No. 3

Dugri siphon 1 Upstream (before remodelling) January 1929
:owing holes (h) Drilled by compressor for letting in reinforcement to connect the old and new work.
lark the seam of cement grout (CG) done in 1925 which has effectively filled in the big crack

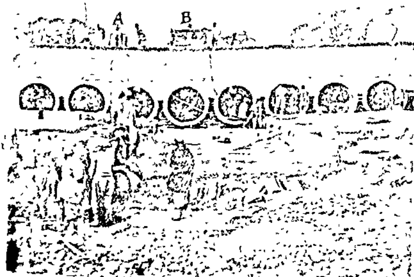
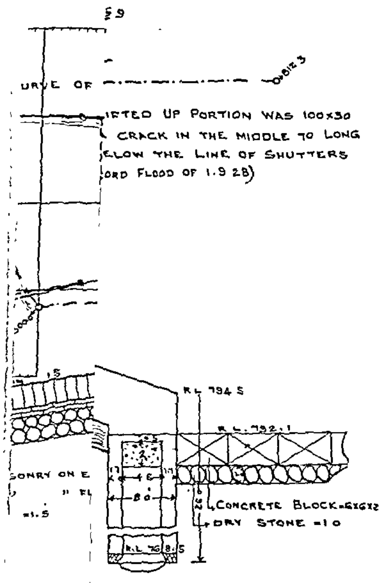


Photo No. 4.

Dugri siphon Upstream ... Note the ... eumatic dr... ure and ... asure with ...


59
URVE OF
0.812 3
IFTED UP PORTION WAS 100x30
CRACK IN THE MIDDLE TO LONG
ELOW THE LINE OF SHUTTERS
ORD FLOOD OF 1.9 28)
1.5
R.L 794 5
R.L. 792.1
SONRY ON E
=1.5
17
16
17
80
CONCRETE BLOCK=6X6X2
DRY STONE =10
R.L 76 8.5

was also diagramatically explained. The diagram also indicated the [illegible] and downstream pile and well lines [illegible] from plate III of this paper and [illegible]

L. Kanwar Sain said that Mr. Khosla's paper was undoubtedly a great advance on the high road of investigation into the stability of structures resting on saturated soils. [illegible]

[illegible] in the structures, and to record continuously the actual height of water in them."

Out of four weirs on S. V. P. pressure pipes had been put in only at Suleimanke and at Panjnad. At Suleimanke, however, the sheet piles going into the clay, these pressure pipes were only of local interest and would add nothing to our knowledge on the broad principles of this problem. The Panjnad weir had not yet started functioning.' Mr. Khosla had, therefore, perhaps of necessity, to fall back mostly on the Narora Weir data in order to support his observations at the Dugri No. 1 and the Jauryan Syphons, and thus gave them an opportunity of comparing the data on which Bligh based his theory with Mr. Khosla's own more exhaustive observations.

Mr. Khosla admitted frankly in his paper that the Narora Weir was standing in spite of the Bligh line being dangerously below the actuals. One of the reasons he gave for this was that water could not exert full upward pressure on the entire area of the floor which was in contact partly with the soil particles and partly with water, also that the effective area on which the full hydrostatic pressure could act was a function of the porosity of the foundation soil. Thus the average uplift pressure under the floor would be a certain percentage of the indicated pressure. Now it might be noted that Bligh's [illegible] on the fineness or coarseness c[illegible] might be that Bligh in his fars[illegible] clusions based on the Narora [illegible] also made it doubtful how far the rise of water in pressure pipes could serve as a direct measure of the hydrostatic uplift on the floor: for as long as there is no cavity underneath the floor, the full upward pressure indicated by the pressure pipe did not come into play and the formation of a cavity showed that the failure had already started by undermining or 'piping'.

Regarding the hydraulic gradient line being straight or otherwise he would draw attention to Mr. W. B. Gordon's remarks in Technical paper No 97, page 29, "the proposition illustrated in his Fig. 1 (i.e.,

Would Mr. Khosla please modify this impression or confirm it ?

[illegible] difficulty in actual working provided a working plan had been clearly thought out beforehand.

On page 206, Mr. Khosla said the reinforcement of the bottom slab was calculated both for uplift and for *settlement due to cavitation underneath*. Might he enquire what was the size of the cavity assumed in the calculations ? He doubted, if such reinforcement was necessary. He was of opinion that R. C. box construction would be cheaper and much sounder than a gravity section in the normal floor of a Weir.

Mr. Mithal thanked the author for mentioning him in the paper. He desired to associate himself with the deductions and theory brought out by the author.

Mr. G. Lacey said that the paper was a valuable contribution to the [illegible] publication of Mr. Khosla's paper. It would be improper to state that the general theory of hydraulic gradients as laid down by Bligh in his text-book had "gone by the board" and it would be a poor tribute to an engineer who had presented the profession with a useful working [illegible] taken into account when calculating the length of the path of the subsoil water. The implication in this theory was that the loss of head as between piles and sand, or between masonry and sand, was only half that between sand and sand. For this there was little experimental justification on a large scale. The theory was that water would always creep meticulously round the outline of a masonry work where the path was assumed to be of less resistance, rather than strike boldly across a gap of sand pure and simple, for this reason it was sometimes known as the "musk rat theory" as that animal always skirted the boundaries of a room, however complicated, rather than strike across it.

Since Bligh assumed half the resistance, when the sand was in contact with masonry, it was quite clear that if a sandy embankment filled with water had a real hydraulic gradient of 1 in 7.5, the same material if underlying a weir must be given a value of 'c' of 1 in 15. This point was seldom brought out sufficiently.

chain of reasoning that the result held though the relation of the levels was reversed.

3. The speaker failed to understand Mr. Khosla's use of the word "bound" on page 107, and also had grave doubts as to the accuracy of his suggestion that the full hydrostatic pressure was not brought to bear on the floor, for the reason given

The only way in which Mr. Khosla's explanation was tenable lay in imagining the floor perched on a large number of earth pillars of relatively small diameter but large total area. Moreover Mr. Montagu suggested that the American theory to which Mr. Khosla had referred, was applicable to the case of pressures behind vertical retaining walls and not horizontal floors.

4. Mr. Khosla made a statement on bottom of page 197 and top of page 198 which appears to be in the nature of a general statement of a law, whereas it was in reality a statement of an unusual effect at one place only. If Mr. Khosla's general theory were true (and the speaker was convinced of this) then the response of the L. S. W. L. to canal

Clearly it was in such cases that the maximum danger was to be feared.

he similar
levels and
that the

velocity varies with the difference in levels, if not actually wrong, was only a rough approximation. Consequently the statement that the variation in the second case is directly with the differences, was subject to the same criticism. The speaker emphasized that the deduction was wrong and not the curve.

6. The author of the paper had been at some pains to show that Bligh's theory was unsound and on page 201 had compared the effect of a pile line according to Bligh with actuals The speaker suggested that a better comparison was as follows:—

Bligh 18 feet pile $=18\times2=36$ feet length $36\times\frac{1}{15}=2{\cdot}4'$ loss of head.

This loss is constant.

In practice it was found that with high heads upstream, (9·8 feet) as much as 4·65' head was lost over the pile line whereas with low heads upstream (4·1 feet) the effect of the pile line was only 1·9 feet.

It followed that *deep pile lines* and wells were generally *more effective than Bligh thought at high heads and less so at low*

of obtaining
was notable

The outstanding lesson of Mr Khosla's analysis of this failure was the necessity of impervious bottom layers of masonry on the downstream glacis.

8 In connection with Mr Khosla's remarks on Suleimanki Weir, the speaker agreed as to the advantages of a sheet steel pile line at the downstream edge of the glacis but this line of piles must on no account be driven into the clay layer.

If the pressure applied by the upstream water level, and found to exist under the glacis was communicated through the interstices of the existing pile line under the crest, then to drive the new pile line down to clay was courting sure disaster.

9. In connection with hydraulic laboratory experiments, the speaker's recent visits to Poona and Karachi had reminded him in no uncertain manner of the difficulties involved in model experiments

i. The scale factor affects velocity and rugosity in a proportion different from that of the scale.

ii There is no silt movement below 0 88 f p.s.

iii. Any natural swirl assumes its full size: in a model whose vertical and horizontal scales are not the same, this destroys the relation at once.

The speaker therefore supported a plea for research on a full or natural scale, into the problems set forth by the author.

10 The speaker held that the author's conclusions were warranted *on the whole but urged caution in regard to*—

i. wholesale condemnation of Bligh whose *results* if not his methods were sufficiently accurate for working rules over a long period of years,

ii. relief strainers: the speaker repeated and emphasized his reasons for distrust of this device.

11. Mr Montagu concluded with a plea for a reasoned nomenclature and notation.

Mr. A. A. Musto, referring to page 197 (1), questioned whether

With reference to para. (2) on that page he said that Bligh himself gave a margin of 33 per cent. for safety. It was hardly fair to blame Bligh for errors in his theory, only discovered as the result of applying this theory to designs. Previously there had been no theory and only rule of thumb design. Bligh as a pioneer had done a great service to design however many mistakes there might be in his original tentative theories. The unbalanced head (non-apparent) referred to by Mr. Khosla ought to be very small if piping had not started and if the correct efficient of creep had been taken for design. It seemed to him inconsistencies and dangers observed in existing old works were

always much more probably due to *faulty work*, *e g*, non-watertight lines of wells, than to mistakes in design or theory.

He doubted if all these works were protected from creep of subsoil water at their ends *i.e.*, *along the river banks* as well as in the direction of river flow; if not, they would fail from this direction. When designing, the *whole plans* of the work must be studied for protection and not merely a cross section in the direction of the river.

No complete *plans* were shown in the papers. Surely if a scour hole *beyond* the end of the pacca floor (toe wall) caused piping it could only be because the co-efficient of creep had been taken too low in the design. Of course if scour were allowed to come right back to the toe

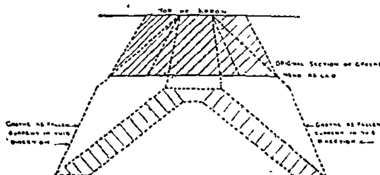
the toe wall by providing an ample falling apron which would keep scour held up *at a distance*.

As cross currents *i.e.* currents parallel with the edge of the falling

upstream and downstream) he suggested, throwing out groynes of pitching stone beyond the edges of such aprons thus:—



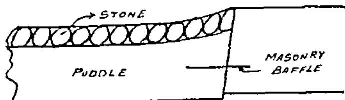
These groynes would fall sideways (with cross currents passing over them) and they should be much thicker at upstream or outer ends than at the edge of apron. They would then fall in this form:—



The spacing, contents and form of groyne would need care consideration. The above was only a rough suggestion.

Re erring to the *Narora Weir* the speaker said that an upstream puddle apron was in his opinion unrel able, as it was practicall to make a watertight junction between puddle and a *verti*

either masonry or steel piling. The slightest settlement or contraction of the puddle would break what slight seal had been obtained by puddling against the wall. The only way to obtain a seal would be on to horizontal baffles built into the wall and surrounded by puddle. Even with this, uneven settlement might cause shear through the puddle and give a leak.



It was also doubtful if either of the lines of wells under the floor are really watertight. This was probably the main source of weakness in the floor.

Referring to *Rasul Weir* the speaker asked what was a Kharanja. When local terms were used they should be explained.

It seemed bad policy to lay masonry on dry stone filling which was almost certain to settle or compact itself and thus give irregular support to the masonry and even if the masonry did not crack and settle would leave pipes for flow of water below it. Would it not be better to lay the masonry direct on to the compacted sand?

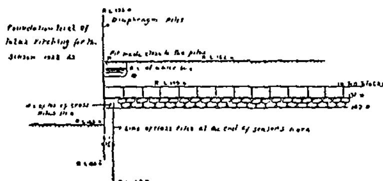
Referring to the *Marala Weir* he asked how the "hollow underneath the concrete blocks laid to replace the lifted Kharanja layer" was observed. Were not these raised cills a source of danger? Would not a lower cill (plus rising gates) get over much of the standing wave difficulty?

block should be not less than $9 \times \frac{62{\cdot}4}{{\cdot}125} = 4\frac{1}{2}$ ft.

Referring to *Suleimanke Weir* he said that the greater effect of vertical lines of obstruction *i.e.*, piling as compared with horizontal obstruction was due to the fact that any sand displaced against sides of piling was immediately replaced by further sand falling from above whereas sand removed from under the horizontal masonry would only be replaced by further sand carried by the stream of water and left deposited there. If piping once started it was unlikely that sand would ever be re-deposited in these pipes.

He attached 3 sketches with particulars of 4 tests of actual creep factor at Sukkur which might be of interest to members. These were recorded by Mr. M. P. Mathrani, Executive Engineer, Left Work Division, and verified by the speaker.

EXPERIMENTS OBSERVED BY MR. M. P. MATHRANI, EXECUTIVE ENGINEER, LEFT WORKS DIVISION, AND VERIFIED BY MR. A
NEER, LLOYD BAR
CO-EFFICIENT OF
RIVER SAND) AND



Sketch showing the difference of water level on the two sides of diaphragm piles at the end of season's work (1927-1928).

Co-efficient of creep $\frac{(R. L. 180-149)+(165-149}{15}$

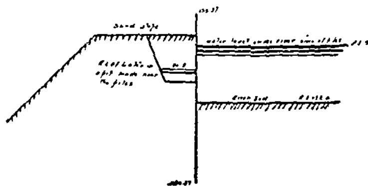
$$= \frac{31+16}{15}$$

$$= \frac{47}{15}$$

$$=3{\cdot}2$$

Possibly these piles passed through a layer of clay.

(2) Sketch showing the water-level on two sides of Cofferdam piling (season 1928-29), 27th May, 1929.

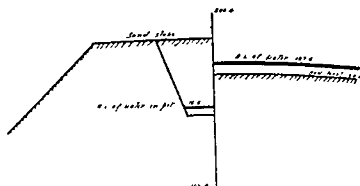


Length of creep on river side of piles = 172·0—150·37
= 21·6

Length of creep on cofferdam side of piles = 180·8—150·37
= 30·4

Co-efficient of creep.. $\frac{52{\cdot}0}{6{\cdot}5} = 8.$

(3) Sketch showing water levels on two sides of cofferdam piles near flume No 5 (season 1928-1929) 30th May, 1929.



$$\text{Co-efficient of creep} = \frac{(184{\cdot}0-155{\cdot}4)+(176{\cdot}8-155{\cdot}4)}{10{\cdot}8}$$
$$= \frac{28{\cdot}6+21{\cdot}4}{10{\cdot}8}$$
$$= \frac{50}{10{\cdot}8}$$
$$= \text{About } 5.$$

(4). It is found that a sand bund can stand a hydraulic gradient or 1 in 3 (with a total head of 18′ of water) without breaching. But under these conditions sand is always on the move.

If the section is wide enough to give a hydraulic gradient of *1 in 4*, there is practically no movement of sand, but water simply oozes *gently* at the toe. This has been tested on various occasions (up to *18′ head*).

Mr. Khosla, in reply to Mr. Kanwar Sen, appreciated *Mr. Colyer's* remarks suggesting extensive use of stand pipes for *finding out the true* laws of hydraulic flow as affecting the weirs. The question of *upward* water pressure acting on the whole or a part of the area was taken *up by* practically all the speakers.

Little experimental data existed on the subject but it [illegible] that water in the capillary state could not exert the [illegible] pressure; some tests were being carried out at Ferozepore [illegible] of these tests would be valuable when made available [illegible] went they helped to support the theory put forward [illegible] is- Mr. Burkitt ascribes this phenomenon to the surface [illegible]

microscopically small filaments of water between the grains of sand, which tension must be enormous and must act exactly like friction. A confirmation of this view could be had from the floor of the Passia siphon of the Upper Chenab Canal where the weight of the floor slab plus that of the middle and side walls was only 65 to 75 per cent. of the total indicated pressure and yet that light floor was standing intact. Careful experimental work was required to determine the exact percentage of indicated pressure which should be allowed for in designs. In the text, the phrase " water in bound state " had been used. It was the same as water in the capillary state. Directly, water under

[illegible]

the capillary or bound state, and would start exerting increasing upward pressure on the underside of the structure till in the limit this would get in contact over the whole area with a continuous sheet of water and the full indicated pressure would be exerted. Other points in this respect had already been explained in the text.

[illegible] definite area of pipes, a condition where the depth of subsoil was ·refore, indicated large velocities.

Mr. Kanwar Sen had rightly summed-up the conclusions which the author had in view in writing the paper. He, the writer, agreed that a monolithic form of concrete construction as was being done at Panjnad was the best possible safeguard against uplifts of the type that occurred at Marala and Rasul.

The bottom reinforcement of the floor slab was calculated on the assumption that the maximum cavity would not exceed half the effective span of the slab.

Regarding the difference between a reinforced concrete and a gravity section, there were both advantages and disadvantages. The gravity section was more elastic and therefore local damage could be spotted and set right much easier, but the reinforced concrete floor gave no indication of trouble until large cavities had occurred, which resulted in the first and final collapse

Mr. Lacey introduced an important point that according to Mr. Bligh the resistance along sheet piles or masonry face was half of that which existed in sand. His remarks in the last paragraph were instructive.

Mr. Colyer suggested tests in the laboratory with which the author was in whole-hearted agreement.

Regarding soda cement, the proportions generally used were 1 in 1, to 1 in 4: the more the soda the less the strength.

The relief pipes were generally fixed 10 to 15 feet apart, or as the local conditions suggested

The true free water surface is determined by inserting a filter point in the open bed of drain or river till such depth that the indicated water level in the pressure pipe does not rise any further. This driving should be done gradually to get good results

The author was in general agreement with Mr Colyer regarding the element of risk involved in having the tail end of the pacca floor resting over a pervious layer of stone and shingle Mr. Musto had drawn attention to this very point The best practice would apparently be to rest the pacca floor on compacted sand and give a length of thick inverted filter covered over with suitable thickness of blocks, just below this pacca floor

Mr. Montagu's suggestion regarding logarithmic plotting was accepted with thanks, as it would help matters a great deal, and probably bring forth fresh ideas

Mr. Montagu had rightly drawn attention to the fact that a line of sheet piling or wells became more effective as the head increased—a fact which Bligh had not allowed for The loss of head—as mathematically established by Dr Bose for intermediate sheet piling—varied with the velocity of under flow, *viz*, $hp = v \times 2c$. Bligh had considered the length 2c but had not suspected the variation with v—the velocity. This explained why sheet piling became more effective at high heads.

The calculation of standing wave was based on Mr. Burkitt's method. He fully supported the suggestion of carrying out model experiments and experiments on full sized structures

He also agreed with Mr. Montagu regarding the doubtful utility if not the utter uselessness, of relief strainers and regarding the change in nomenclature of some of the terms used in the paper

In reply to Mr. Musto, he said that the question of uplift pressure had already been dealt with in reply to other speakers' criticisms Mr. Musto's contention that the sand particles in contact with the under-side of the floor slab were themselves under equal upward pressure, was correct, but these particles had their own weight acting downwards and as such could not transmit the full upward pressure to the floor slab. The author associated himself in appreciating the basis laid for the engineering profession by Mr. Bligh This paper was in no way intended to belittle Mr. Bligh's efforts. Knowledge was a process of evolution and as such the new advance on old ideas was quite natural

Regarding pressure from the sides, this question had already been considered in some of the recent designs and sheet piling was consequently provided upstream, downstream and on the flanks.

He also agreed with Mr. Musto that puddle never made a [illegible] factory joint with a pacca vertical face.

Kharanja meant stone on edge. The settlement of the floor below the blocks (or slabs) laid in 1929 occurred above winter water level and could therefore be distinctly seen in the dry.

The author finished by thanking the various speakers for the interest they had shown in the paper as evidenced by the discussions.

The President, in winding up discussions on Mr. Khosla's paper, thanked him on behalf of himself and all the Congress Members for the very interesting paper, which will greatly stimulate further investigation into the subject. He also thanked Mr. Musto for his candid criticism and assured him that the papers in future will see all the improvements so kindly suggested by him.

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It is suggested that drawings foolscap depth with $\frac{1}{8}$" stencilled lettering or double foolscap depth with $\frac{1}{4}$" stencils be

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Serial number.

1. Grain Elevators and their application to the Punjab Wheat Transport Problem.—Victor Bayley.
2. The formation of land by rivers and torrents in the Punjab.—A. J. Wadley.
3. Auxiliary Reservoirs for Irrigation in the Punjab.—C. E. Blaker
4. Dams and Storage Reservoirs.—F. W. Schonemann.
5. Concrete Work in Loco. Shops, Lahore.—J. A. Bell.
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7. The Mechanical Equipment of Irrigation Works.—John Ashford.

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8. The Hindustan—Thibet Road.—A. R. Astbury.
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12. Maintenance of Marala Weir.—Cecil A. Colyer.
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18. The Construction of a Double Track Girder Bridge across [illegible] Railway between [illegible]
19. [illegible] Carriage Washing at [illegible] [illegible]on, R. E.
20. Research and Investigation Section for the Public Wor[illegible] Department—Cecil A. Colyer.
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22. Water Proofing Operations on the Jhang Branch of the Lower Chenab Canal during 1913-14.—T. A. Curry.
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30. Distributary Off-takes in relation to Silt Conditions.—F. V. Elsden.

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33. The Namal Dam.—Lahna Singh.
34. Sialkot Water-supply.—E. S. Heard.
35. Surface Drainage Schemes in the Punjab.—Amar Nath Nanda.
36. Canal Outlets.—B. P. Varma.

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37. The extension of American Cotton Cultivation under irrigation in the Western Punjab and Sindh.—W. Roberts.
38. The Sub-soil Water Table under the Tract Irrigated by the Lower Chenab Canal.—C. G. May.
39. [illegible] Miller Brownlie.
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83. Tests carried out on Sand from the Sutlej River and Punjab Portland Cement.—A. N. M. Robertson and A. Weighall.
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90. Notes on Aerial Photographs of Canal Works.—E. S. Lindley.

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117. The Sudan Public Works Department—D. Macfarlane.

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123. Bituminous Road Construction—W. S. Dorman.

124. The treatment of water-logged or threatened areas by changes in distribution and supply of irrigation water—B. H. Wilsdon.

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126. Energy of Flowing Water, Critical Flow and Standing Waves—A. M. R. Montague.

127. Extension of the Training Works at the Jumna Bridge near Kalanour—D. C. Varma.

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KENNEDY MEDAL.

Whereas a fund has been instituted in order to give public recognition to the work of Mr. R. G. Kennedy, C.I.E., late Chief Engineer, Punjab, in certain classes of research, and whereas the main object of this fund is to encourage further study and research in irrigation science, and whereas the subscribers to the said fund have determined that this object can best be attained by the grant of a medal to be awarded from time [illegible] ...ally for the best published paper on such [illegible] the follow- [illegible]

1. A medal shall be awarded for the best publishe[illegible] ...er on any of the following subjects :—

(a) the distribution of water for irrigation ;

(b) the condition and flow of subsoil water with its connected problems of losses of absorption within the soil ;

(c) the flow of water, the transportation of silt by currents of water, and the prevention of silting of irrigation canals ;

(d) and generally any kind of research tending to bring about the conservation of water for irrigation or the improvement of canal irrigation and the reduction of evils resulting from irrigation.

2. The competitions are open to all persons resident or employed in or retired from the engineering services in India, whether official or non-official.

3. The papers submitted for competition must either have been published in some engineering or scientific journal or read at some engineering or scientific society, conference, congress or institution prior t[illegible] closing date of the competition.

[illegible] ...determine whether [illegible] ...he award [illegible] ...al.

[illegible] the 1st of

5. The closing date of the next compet[illegible] will close on the 1st of October 1930, and thereafter competition will close on the 1st of October of each year.

6. Papers or the competitions and correspondence should be addressed to the Honorary Secretary, Kennedy Medal Fund, C/o the Under-Secretary, Public Works Department, Secretariat, Lahore.

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[illegible] H.

[illegible] ad, Lahore.

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Dhawan, P. L., Ex. Engr., Railway, N. W. R., Lahore.
Dhand, M. R., Ex. Engr., Railway, N. W. R., Multan.
Diwan Chand Sharma, Asst. Engr., P. W. D, Lyallpur.
Dixon, T., Ex. Engr., Canals, Karnal.
Donald, W. H., Tempy. Engr., the Manor Nagar, Kulu.
Dorman, W. S., Chief Engr., P. W. D., Lahore.
Doroleeff, N. V., Asstt. Ex. Engr., Hydro-Electric Branch, Jogindarnagar.
Downing, F. H., Asstt. Ex. Engr., N.-W. F. P.
Dundon, G. H., Ex. Engr., Canals, Ferozepore.
Dutt D., Ex. Engr., N. W. R., Lahore.

Easten, T. W. R., Asstt. Ex. Engr., Agr. College, Lyallpur.
Eccleston, W. T., P. W. D., 113, Finance Road, Rawalpindi.
Edwards, C. A. H., Ch. Engr., N. W. R., Lahore.

Fakhar-ud-Din, Ex Engr., Irrigation Secretariat, Lahore.
Fane, A G C, Supdg. Engr., Ambala.
Faqir Mohammad Khan, K S., Ex. Engr., Canals, Jhang.
Farquharson, F. A., I B Sectt., Lahore.
Fenwick, E. N., Ex. Engr., Bahawalpur.
Ferne, A., Ex Engr., P W D, Sectt., Lahore.
Fletcher, J. H., Ex. Engr., Irrigation, Multan.
Foster, F. R., Kulti, P O. (E. I. R.)
Foy, T. A. W., Ex Engr., Canals, Rasul.
Freak, L. A., Secretary Communication Board Punjab Lahore.

Ganpat Rai, R B., Ex. Engr., Irrigation, Multan.
Gautam, D. N., Sart khrsrh.
Ghani, M. A., S D. O., P. W. D., Jhelum.
Ghulam Gaus Khan, Divisional Officer, Rahimyar Khan.
Gilbert, G., Ex. Engr., P. W. D., Jhelum.
Girdhari Lal, Lala, Asstt. Engr., Irrigation, Kot Naja, District Sargodha.
Gita Ram Garg., Ex. Engr., Irrigation, Ludhiana.
Glass, F. C., Special Irrigation Officer, Bikaneer State, Ferozepore.
Goel, J R., Jammu.
Goodman, R. T W., Asstt. Ex. Engr., c/o Ch. Engr., N.-W. F. P., Peshawar.
Goyal, N P., Asstt. Ex. Engr., Khanpur.
Gunn, J P, Ex. Engr., Irrigation Secretariat, Lahore.
Gupta, K. L Asst. Ex Engr., Bahawalnagar.
Gupta, R K., S. D. O., Rasul.
Gupta, H C, Ty Engr., Canals, Chakorie, P. O. Bagrianwali.
Gupta, L S., Asstt Ex Engr., Canals, Rohtak.
Gurandıtta Mal Khosla, S D. O., Public Health Sub-Division, Sialkot.
Gurbakhsh Rai Chopra, S. D. O., Irrigation Branch, Mittru.
Gurbachan Singh, Lam[illegible]
Gurbakhsh Singh, S. B[illegible]
Gurcharan Dass Mehta [illegible]
Guthen, A Capt., R E [illegible]
Gwyther, R F., Ex [illegible]
Gyan Chand, R S., F [illegible]

Habib Ullah Mir, S D. O., Irrigation Sehna, P. O. Bhatinda.
Hadow, R P., C I.E., Ch Engr., Irrigation, Punjab, Lahore.
Haigh, F F., Ex. Engr., Irrigation Secretariat, Lahore.
Hakim Ray, Lala, S. D O., Canals, Bathinda
Halifax, H. W., Ex. Engr., P. W. D., Jaipur.
Hall, W. S., Asstt Ex. Engr., P. O. Pullah.
Hammond, L. Major R E [illegible]
Handa, R I[illegible]
Hanley, P. J[illegible]
Haq Nawaz [illegible]
Harbans Lal [illegible] Canals, Rohtak.
Harbans Rai, P. W. D., Provincial Division, Sargodha.
Har Bhagwan, S. D. O., Canals, Kahror Pucca.
Hari Kirpal, Asstt. Engr., Malkani, P. O Khanpur, (Bahawalpur State).
Hari Lal Sally, S. D. O., Canals, Vihari, P. O. Burewala
Hari Ram, Pandit, Tempy. Asstt. Engr., Durgai, District Peshawar.
Harris, H. A., Ex. Engr., P. W. D, Montgomery.
Hayat, S. M., Tempy. Engr. Irrigation Khanewal.
Hyat, S. M., Tempy. Engr., Canals. Sheikhupura.
Hawes, C. G, 9, Mary Road, Karachi.
Head, G. B. D., Barrage Township, Sukkur.
Heathcote, L. H. M., Supdg. Engr., P. W. D., Multan.
Hetherington, F., c/o McLeod & Co., McLeod House, Calcutta.
Hindley, O. W., Supdg. Engr., Canals, Delhi.
Horn, D. J., 30, The Mall, Lahore.

Howell, D. A., Ex. Engr., P. H. Division, Lahore.
Hughes, I. D. E., Supdg. Engr., Irrigation, Bahawalpur.
Hukam Chand, R. B., Ex. Engr., Lower Gugera Division, Lyallpur.
Hukam Chand, Nath Niwas, Bhati Gate, Lahore
Hunt, G. H., Ex. Engr., Hydro-Electric Department, Palampur.
Hutton, G. T., Falletti's Hotel, Lahore.

Ilahi, S. M., 2nd Agr. Engr., Lyallpur.
Indar Singh, Ch. Boiler Inspector, Lahore.
Indra Sein, B A, S. D O, Marh, Chichokimalian.
Inglis, C. C., Supdg. Engr., Irrigation Research and Development Poona.
Iqbal Hussain, K. S, Ex Engr, Rural Sanitary Board, Punjab, Lahore.
Ishar Das, Lala, S. D. O., Pakpattan.
Ismail Hussain, S, S. D. O., Shahdara Sub-Division, Shahdara, (near Lahore).

Jafar, A. M., Asstt. Engr, P. W. D, Multan.
Jagan Nath, Lala, S D. O., P. W. D., Amritsar.
Jagan Nath, Pandit, Asstt. Principal, Rasul.
Jagdambe Sahai Mathur, S D. O, Irrigation, Qaimpur.
Jai Ram, Ex. Engr., Canals, Lyallpur
Jaimal Singh Kaley, S D. O, Irrigation, Lodhran
Jaini, D. D., Ex. Engr., Irrigation, Sargodha.
Jaini, J. B., Asstt. Engr., P. O. Mubarakpur.
Janki Nath, S. D. O., Thanesar.
Jefferis, C. E, Supdg. Engr., Hydro-Electric Branch, Jogindarnagar.
Jennett, S, Asstt. Ex. Engr, Irrigation, P O Nabki, Distt. Gujranwala.
Jesson, A. W. M, Supdg. Engr., Canals, Sargodha
Johnston, J. H, Ex. Engr., P W. D. Lahore
Jones, R. T., Ex. Engr., P. W. D Sectt., Lahore
Juneja, J. N., Ex. Engr, Sargodha.

Kanwar Sein, Lala, Asstt. Ex Engr, Jaman Sub-Division, P. O Amritsar.
Kapur, B. D, S. D. O, N. W. R., Lahore
Kapur, B. K, Ex. Engr, Lyallpur.
Kapur, F. C, 1, Mason Road, Lahore.
Kashyap, H L, Hydro Electric Department, Lahore.
Kennedy, T. S., c/o Messrs. Glenfield & Kennedy, P. O. Box 443, Bombay.
Kewalramani, K. B, Asstt. Engr, Canals, Balloki.
Khanna, A. D, Asstt. Engr, Bahishti, P O Lodhran.
Khanna, A. R., Headworks, Madhopore
Khanna, P. C., S. D. O, N W. R, Karachi
Khanna, D C., Public Health Circle, Lahore.
Khan, M. A., Ex. Engr, P. O. Shewa, District Peshawar.
Khan, M. M., Okara Division, Montgomery
Khanda Ram, Tempy. Engr., Irrigation, Sidhnai.
Khushi Ram, Lala, S. D O, P. O. Sadiqabad.
Khushi Ram Sud, S. D O, Panjnad
Kidar Nath, Lala, S. D O, P W. D. Sub Division, Ambala.
King, C., Post Box No. 91, Lahore.
Kishen Singh Sowanni, B Sc., Water-Logging Com, Lahore.
Kumar, S. L., S. D O., Railways, Khanewal.
Kundan Lal, Lala, R. S, Ex. Engr, P. W. D, Ferozepore.

Labhu Ram Kaley, Ex. Engr, Irrigation, Amritsar.
Lacey, G, Ex. Engr., Thomason College, Roorkee.
Lakshmi Shankar, S. D. O, N. W. R., Kasur.
Lal Chand, Lala, S D O, P. W. D, Jullundur.
Leggett, S, Central Workshop, Amritsar.
Lindley, E. S., c/o Messrs. Thos. Cook and Sons, Berkley St. Piccadilly, London.
Livingston, Learmonth, A. P., Ex Engr., Irrigation, Sargodha.
Lyster, A. St. G., N. W. F., Malakand.

Macfarlane, D., Offg Dy Secy., P. W. D , Lahore.
Mackinnon, J , X E N N W. R , Lahore
Macrae, W. Lt Col Dy Ch. Engr , N W R , Lahore.
MacMillan, N B , Ex Engr , Hydro Electric, Lahore.
Madnani, T B , Ex Engr , Public Health Division Multan
Main, B F , Ex Engr , Public Health Division, Ambala.
Majid Ullah, Asstt Ex Engr , Ahmadpur Lamma.
Makhan Lal, R B , 8 , Edwards Road, Lahore.
Malhotra, S L , Irrigation Department, Jahar, District Montgomery.
Malik, A B , S D O , Irrigation Sheikhupura.
Maneckshaw, N H F , Temy Engr , P O. Aminpur, District Jhang
Mangal Sen Dhody, R B , Supdg Engr , Irrigation, Jhelum.
Mangat Singh, Bh , Ex Engr , Irrigation, Rohtak.
Mann, E D , Tempy, Engr., Delhi Div , Delhi.
Masud Ahmad Rashid, Asstt Engr., P. O. Bunga Sahib Ka.
Mathur, B G , S D O , Rai Singh Nagar, Bikaner State.
May, B H , Ex Engr , Lahore.
May, J D , Ex Engr , Gurdaspur.
McKenna, C H , Ex Engr., Sulemanke
McLeod, W. N , Supdg Engr , Hydro-Electric Department, Lahore.
McPhail, D S , Ex Engr , Hydro-Electric Branch, Jugindarnagar.
Mehr Chand, Lala, Ex Engr , P. W. D., Dharamsala.
Mehr Chand, Ex. Engr , Irrigation Branch, Bahawalnagar.
Mehta, D. D P. O Jalwala.
Menezies, J. A. S , Tempy. Engr., Irrigation, Bathinda.
Merrington, H J , P O Panjnad.
Miller, A E. J , Asstt. Ex. Engr., Pakpattan.
Milne, F L , Electrical Engr., to Govt , Punjab, Lahore.
[illegible] K. R , Ex Engr , Irrigation, Rahimyar Khan.

Mohd Anwar Husain, Asstt. Engr , Bahawalpur.
[illegible]

[illegible] nbrial.
[illegible] alia
[illegible] adiqia.

[illegible] ok

Nand Kishor, Asstt. Engr., P. O. Mambrani.
Nand Gopal, Ex. Engr., Irrigation, Sheikhupura.
Nariman, R. K , Ex. Engr., Patiala.

Nar Singh Dass Kapur, Mochiwala Rest House, P. O. Killa Ram Kaur.
Natha Singh, R. B., Supdg. Engr., Irrigation, Multan.
Naunidh Rai, Asstt. Engr., Irrigation, Jagraon.
Nayar, D. P., S. D. O., P. W. D., Gurgaon.
Nicholson, H. W., Supdg. Engr., Irrigation Secretariat, Lahore.
Nilkanth Shore, Asstt. Engr., Canals, Shah Jiwana.
Niranjan Das Gulhati, Asstt. Ex. Engr., Irrigation, Samalia.
Nok Chand, Asstt. Engr., Discharge Division, Irrigation Secretariat, Lahore.

Oram, A., Supdg. Engr., Irrigation, D. I. Khan.
Oram, W. C., Ex. Engr., P. W. D.

Padday, A. C., Supdg. Engr (retired), c/o Lloyd's Bank, Bombay.
Parma Nand, R. S., Asstt Engr., Irrigation, Jatli Sub-Division, Jatli.
Pavry, F. C., Ch. Engr., N. W. R., Lahore.
Perry, A. S. H., Supdg. Engr., Canals, Lahore.
Pound, G. T., Ex. Engr., Provincial Division, Lahore.
Prabh Singh Chawla, S. B., 49-A, Mozang Road, Lahore.
Pria Das Tandon, R. S., Ex. Engr., Gujranwala.
Protheroe, E. L., Ex. Engr., Irrigation, Montgomery.
Puri, P. C., Asstt. Ex. Engr., Canals, Sargodha.
Puri, M. R., S. D. O., Drainage, Gurgaon.

Quinton, W. G., c/o Lloyds Bank, Ramsey Hants, England.

Radhika Lal Popli, Mehta, Divisional Officer, Rahimyar Khan.
Radha Lal, Resdt. Engr., Lake Road, Lahore.
[illegible] iat, Lahore.
[illegible]
Ram Rakha, R. B., Ex. Engr., Ferozepore.
Ram Saroop, Asstt. Ex. Engr., Ludhiana.
Randhir Singh Sanghera, S. D. O., Ludhiana.
Rashid Khan, M. M., S. D. O., N. W. R., Bahawalnagar.
Rayner, A. B., Ex. Engr., Irrigation, Gujrat (Punjab).
Richardson, H. C., 30, The Mall, Lahore.
Roberts, W., Khanewal.
Robertson, A. N., Mcl., c/o Irrigation Secretariat, Lahore.
Robey, E. B., Dy. Ch. Engr., N. W. R., Lahore.
Rose, R. F., Asst. Engr., Canals.
Ross, G. M., State Engineer, Bahawalpur.
Roy, J. L., Ex. Engr., Canal Colony, Panjnad.
Ryan, B. J., Ex. Engr., P. W. D., Jaipur.

Sahib Dyal Kalra, S. D. O., Sadiqia (Bahawalpur State).
Sahney, R. L., Tempy. Engr., Canals, Gujranwala.
[illegible]

Saroop, B., 31, The Mall, Lahore.
Sarup Singh, Asstt Ex Engr., Montgomery
Sawney, G R., Ex Eng., Canals, Khanewal
Sethi, A.R., S D O., P O. Shaina.
Sethi, J S., S D. O., Public Health, Sub-Division, Lahore.
Sethi, P D., S D O., Canals, Ropar.
Sharma, K R., S D O., Canals, Sargodha.
Sharma K R., S D O. Canals, P O. Bhong via Ahmedpur Lamma.
Sharma F R., Tempy Engr., Mundri Dist. Karnal.
Sharma, S M Asstt Ex Engr., Irrigation, Hissar.
Shauqi Chand, L., S D O., Khudian.
Sheo Singh Bedi, Ex Engr., Irrigation, Rahimyar Khan.
Sher Ali Ismaili, N W. F. P (Irrigation), Peshawar
Sita Ram Mehra, S D O., P. W. D., Burewala.
Sleigh, A L., Divisional Supdt., N. W. R., Lahore.
Smythe, J W., Ex Engr., Irrigation, Bhamba, via Raewind
Smith, J B G., Chief Engr., Irrigation, Lahore.
Sohan Lal Nayar, S D. O., P. W. D., Dharmsala.
Sondhi, R L., Ex. Engr., P. W D., Gurgaon.
Sopwith, G. E., Lt.-Col., C. R. E's. Office, Peshawar.
Sri Krishan Dass, Asstt. Engr., P. W D., Irrigation, Chakori.
Sri Ram Puri, S. D. O., Drainage Sub-Division, Gurgaon.
Sri Ram, Asstt. Engr., P W D., Sargodha.
Sulakhan Singh Sohl, Asstt Engr., Irrigation, Multan
Sullivan, B. M., Supdt Architect, Punjab, Lahore.
Sundar Dass Khangar, Asstt Ex Engr., Qaimpur.
Sundar Dass Pahwa, Tempy. Engr., Rahimyar Khan
Suraj Bhan, Ch., Asstt Engr., Irrigation, Khanewal.
Swami Dass, R. S. Lala, "A" Sub-Division, Lahore.
Sylvester, H. F., Asstt. Ex. Engr., Eastern Bar Division, Montgomery.

[illegible] P. O. Gojra.
[illegible], District Gujrat.
[illegible] ct Kangra.
Tate, T. B., Supdg Engr., Bikaneer Circle, Ferozepore.
Tej Ram, R. B., Ex. Engr., Retired, 7, Rattigan Road, Lahore.
[illegible]

[illegible] Asstt. Engr., Irrigation, [illegible] Division, Sargodha.
Townsend, F. O., Ex. Engr., Bahawalnagar.
Turner, P. A., Asstt. Engr., Canals, Marala.

Uppal, B. L., Ex. Engr., Muzaffargarh.

Vaish, K. C., Tempy. Engr., P. W. D., Sheikhupura.
Varma, A. P., R. B., Supdg. Engr., Ferozepore.
Varma, B P., R. B., Ch. Engr., Irrigation, Lahore.
Vardon, J. A., Ex. Engr., N. W. R., Lahore.
Vas Dev Bhandari, Asstt Ex. Engr., P. O. *Dera Nawab.*
Vasu Dev, S R., Asstt. Engr., Irrigation, Bathinda
Vesugar, J. B., Ex. Engr., Provincial Division, *Lahore.*

Waghorn, R. D. Capt. c/o Imperial Bank of India, Lahore.
Waller, F. J., Supdg. Engr., 3rd Bahawalpur Circle, Bahawalpur.
Walton, C., Col., D. S. O., 2, Mayo Gardens, Lahore.

Watson, N. G., Ex. Engr., c/o Messrs. Thomas Cook & Sons, Ludgate Circus, London.
Wazir ([illegible] East Circle, Lyallpur.
Wazir [illegible]
Wheatl [illegible] London, W. 1.
Wilsdor [illegible]
Willian [illegible]
Wells, [illegible]

Yog Raj Puri, S. D. O., P. W. D., Rohtak.
Youngson, A., Temy. Engr., Irrigation, Gujranwala